COMPARATIVE EVALUATION OF THE EFFECT OF CYCLIC LOADING ON THE REVERSE TORQUE VALUES OF ABUTMENT SCREWS FOR PREMACHINED TITANIUM AND ZIRCONIA ABUTMENTS - AN IN VITRO STUDY

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CERTIFICATE

This is to certify that the dissertation titled **"COMPARATIVE EVALUATION OF THE EFFECT OF CYCLIC LOADING ON THE REVERSE TORQUE VALUES OF ABUTMENT SCREWS FOR PREMACHINED TITANIUM AND ZIRCONIA ABUTMENTS - AN IN VITRO STUDY"** is a bonafide record work done by **Dr.J.ABIRAMY BHARATHI** under our guidance and to our satisfaction during her post graduate study period between 2010 – 2013.

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ABSTRACT

Purpose of the study: Comparative literature on the effect of cyclic loading on the reverse torque values of abutment screws for premachined titanium and zirconia abutments are inadequately documented.

Materials and methods: Ten premachined titanium (Group I) and zirconia (Group II) abutments were connected to implants using a digital torque meter. Reverse torque values to loosen the abutment screws were measured before cyclic loading. Cement-cum-screw retained prostheses were fabricated and cemented on each abutment and all twenty samples were subjected to cyclic loading simulating 6 months of function. Reverse torque values were measured after cyclic loading. The results were analyzed using Paired and Independent‘t’ tests.

Results: Cyclic loading resulted in the significant reduction ($p<0.05$) of the reverse torque values for both premachined titanium and zirconia test samples. On cyclic loading titanium abutments had greater reverse torque values and lower reverse torque difference than zirconia abutments.

Conclusion: Both premachined titanium and zirconia abutments exhibited a decrease in reverse torque values before and after cyclic loading. The decrease in reverse torque value was significantly more in zirconia abutments than titanium abutments.

Keywords: titanium abutment screw**,** reverse torque value, reverse torque difference, cyclic loading, digital torque meter

INTRODUCTION

One of the most dramatic services the dental profession has to offer is the replacement of missing teeth with implants.[54] The use of dental implants to support and retain dental prostheses has been demonstrated and proved to be clinically efficacious for both partially and completely edentulous situations.[21,39]

Currently, a majority of partially edentulous situations restored with single-tooth implant supported restorations employ a two-piece endosseous implant and its trans-mucosal component, joined together by the clamping action of abutment screw joint.[24,45,55] Implant restorations over such two-piece implants can be cement-retained, screw-retained, or a combination of both.[38] Cement-retained prostheses provide a less costly and simpler method of fabrication, with a passive restoration.[22,41] They also provide superior occlusion and esthetics when compared to screw-retained prostheses. Although they are commonly used in clinical practice, 'retrievability' of the restorations is the drawback of cement-retained restorations.[22]

Screw-retained implant prostheses are advocated in partially edentulous situations to overcome angulation problems.[6,41] They provide the advantage of retrievability of restorations for reservicing and/or replacement of the restorations. Although screw-retained crown protocol for a single-tooth two-piece implant, is well established, crown complications associated with implant-abutment screw joint integrity are common.[19,37] Their use in the anterior region may be restricted due to esthetic requirements since the screw access channel might open in the labial surface. A cement-cum-screw retained prosthesis combines the “passivity” feature of a cement-retained prosthesis along with the “retrievability” feature of a screw-retained prosthesis and provides an esthetic restoration in the anterior region.[41] Regardless of the type of retention of the prosthesis, screw loosening is a potential risk.[22]

The factors that contribute to screw instability are accuracy at implant-abutment interface, implant-abutment connection design, insufficient tightening force, screw settling, differences in screw material and design and the material properties of the abutment and implant surface. [2,35,51]

The implant abutment interface is a region, where adverse mechanical and biological complications can occur.[25] Mechanical complications include increased incidences of abutment rotation and breakage,[7,43] screw loosening[2,8] and preload reduction and fracture of implant and prosthesis.[2,6,25] Biological complications from microleakage to bone loss have been reported in literature.[25,39]

Long term research has identified mechanical problems with respect to the implant abutment connection geometry.[8,29] Published literature is available in abundance on abutment screw joint stability with external hex connections.[9,13,27,28] Internal hex connection have the advantage of better shielded abutment screw and long internal wall engagement that creates a stiff, unified body to resist joint micromovement when compared to external hex connections.[7,14,55] Very few studies on screw loosening with internal hex connection designs have been reported in literature.[10,21]

The abutment is connected to the implant body by means of an abutment screw by applying torque.[24] Abutment screws are available in various materials such as titanium alloy and gold alloy.[7] When the screw is tightened, it elongates and produces tension from the elastic recovery of the screw called “preload”.[54] The success of a screwed connection is directly related to the preload reached during torque and the maintenance of this preload with time.[6] Preload develops a compressive force between the parts of screw joint called clamping force and is equal in magnitude to the initial clamping force.[24,42,54] When the preload increases, the stability of the screw joint is maximized by increasing the clamping threshold that the joint-separating forces must overcome to cause the screw loosening.[24,42] These external loads cause the vibration and micromovement in the screw joint that leads to the reduction of preload and ends with screw loosening.[24,54] Hence, insufficient tightening force applied to the abutment screws results in screw loosening.[8] Titanium alloy screws are reported to maintain the preload better than gold alloy screws for a given torque for both internal and external hex connections.[50]

The loss of preload is inevitable due to “settling effect” even when an abutment screw is tightened with the recommended torque. It occurs when the contacting spots of a machined implant surface flatten under load, during tightening and loosening procedures.[2,54,55] Screw design variations may also impact screw loosening. Studies exploring the impact of differences in screw design on screw loosening are lacking in literature.

Screw loosening has been reported for all types of prosthesis, including single and multiple-unit restorations. Such failures are common in single implants in the posterior region, since they endure constant forces from chewing, resulting in bending moments.[15, 29] Incisors bear only about one-third to one-fourth of the greatest bite force than that in the posterior region.[15] However, the palatal surface of the anterior teeth provides a vertical “ramp” for the mandibular anterior teeth through protrusive and lateral excursions. Thus, most occlusal loads applied are at an angle to the long axis of the implants which might result in screw loosening. [21,24]

Commercially, premachined abutments are available in titanium, zirconia, and zirconia with titanium connections.[14] Premachined titanium abutments were used traditionally as they displayed superior mechanical properties and excellent biocompatibility. They prevent the occurrence of galvanic and corrosive reactions at the implant-abutment interface, enhancing the peri-implant soft tissue health.[18] However, in the anterior esthetic zone, especially with thin gingival biotypes the use of ceramics for both abutments as well as restorations is warranted.[52] Alumina was the first ceramic abutment material introduced, followed by zirconia, since the latter offers better mechanical and optical properties.[5] Zirconia is now available both as premachined as well as custom-machined (CAD-CAM) abutments.[5,15,53] Additionally, these abutments are also non-toxic, have good tissue compatibility and intrasulcular adaptability.[1,56]

During function, clinical loading may result in micromotion in stable implant-screw joint, which contributes to screw loosening, increase in microgap at the implant-abutment interface and can also cause settling effect.[2,5,8,14,24,27,30,33] This is followed by plaque retention at the interface, resulting in clinical sequelae such as bone loss, peri-implantitis and possible loss of osseointegration.[56] A cyclic loading test is intended to simulate components in function, which permits analysis of possible interaction between abutment screw and loading. Researchers have tested the effect of cyclic loading on different aspects such as, screw loosening, microgap at the interface, surface changes on implant platform and/or screw channel and microbiological assessments. Screw could loosen through compressive loading if applied in a magnitude equal or greater than the preload of the screw. Reverse torque value (RTV) is a measure of resistance offered by the torqued abutment screw to loosening.[24] Measurement of reverse torque value has been accomplished using a torque meter which can be either an analogue type,[2,8,9,24,28,46,50] or more recently, a digital type.[6,17,21,29,40,43] The latter has the advantage of higher accuracy levels coupled with data storage and transfer facility.

Studies on changes in reverse torque values after cyclic loading of premachined titanium abutments connected to titanium implants have been reported.[6,10,27,28,50] However scientific documentation on the effect of cyclic loading on the reverse torque values for premachined zirconia abutments connected to titanium implants is sparse.[15] Moreover, data comparing the effect of non-axial cyclic loading on the reverse torque values of both premachined titanium and premachined zirconia abutments in a single study is lacking.

In view of the above, the aim of the present in-vitro study was to comparatively evaluate the effect of cyclic loading on the reverse torque values of abutment screws for premachined titanium and zirconia abutments using a digital torque meter.

The objectives of the present study included the following:

1. To measure the reverse torque values of abutment screws for premachined titanium abutments before cyclic loading.
2. To measure the reverse torque values of abutment screws for premachined titanium abutments after cyclic loading.
3. To obtain the reverse torque difference of abutment screws for premachined titanium abutments.

4. To measure the reverse torque values of abutment screws for premachined zirconia abutments before cyclic loading.
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11. To compare the mean reverse torque difference of abutment screws for premachined titanium abutments with that of premachined zirconia abutments.
12. To compare overall, the reverse torque values and the reverse torque differences of abutment screws for premachined titanium and zirconia abutments before and after cyclic loading.

REVIEW OF LITERATURE

Breeding LC et al (1993)[10] measured the torque required to loosen single-tooth implant abutment screws of two different systems before and after simulated function. They concluded that one of the systems used exhibited a significant decrease in the amount of torque required to loosen the screws and the addition of adhesive sealant significantly increased the amount of torque necessary to loosen the screws.

Binon PP et al (1996)[8] loaded a series of 10 incrementally larger, machined ASTM Grade 23 titanium non-segmented (UCLA type) abutments off axis with 133 N and cycled at 1150 vertical strokes per minute and 28 counterclockwise rotations per minute to determine screw joint stability. They concluded that there was a direct correlation between hexagonal misfit and screw joint loosening. A rotational misfit of under 2 degrees provided the most stable and predictable screw joint.

Binon PP et al (1996)[9] used the rebroaching technique to evaluate the elimination of rotational misfit on screw joint stability. External hexagon implants of known dimensions were assembled with premachined, cast and rebroached cast abutments. The abutment screws were tightened to 20 Ncm and 30 Ncm, and the same were loaded off axis with 133.3 N. They concluded that there was a direct correlation between rotational misfit and screw loosening. Screw joints can be made more resistive to screw loosening by the elimination of rotational misfit.

Siamos G et al (2002)[42] determined whether varying the preload on the implant-abutment complex would affect screw loosening under simulated loading conditions. Abutment screws in sample models were tightened to 25, 30, 35, and 40 Ncm. One group of samples was allowed to stand for 3 hours after being torqued and then loosened. Another group of samples was retorqued after 10 minutes with the same initial torque value and then allowed to stand for 3 hours before loosening. For the load group of samples, the abutments were torqued into place, retorqued after 10 minutes, and a load applied for 3 hours before loosening. Cyclic loading was carried out within the parameters of this in vitro investigation, the following recommendations can be made: (1) retightening abutment screws 10 minutes after the initial torque applications should be routinely performed and (2) increasing the torque value for abutment screws above 30 N-cm can be beneficial for abutment-implant stability and to decrease screw loosening.

Khraisat et al (2004)[28] investigated the effect of different cyclic loading periods on abutment screw loosening and bending resistance of a single tooth external hexagon implant system. Fifteen Branenmark implant assemblies were divided equally into three equal groups and they were subjected to a cyclic load of 50N for 1X 10^6 cycles , 0.5 X 10^6 cycles and O cycles respectively. They concluded that long term fatigue significantly affected the reverse torque values under centric lateral load

Butz F et al (2005)[12] compared titanium-reinforced ZrO(2) and pure Al(2)O(3) abutments after chewing simulation and static loading. The specimens were exposed to 1.2 million cycles in a chewing simulator. Surviving specimens were subsequently loaded until fracture in a static testing device. Fracture loads (N) and fracture modes were recorded. All specimens but one survived chewing simulation. They proposed that titanium-reinforced ZrO(2) abutments perform similar to metal abutments, and can therefore be recommended as an aesthetic alternative for the restoration of single implants in the anterior region. All-ceramic abutments made of Al_2 O_3 possesed less favourable properties.

Gehrke P et al (2006)[15] assessed the fracture strength of zirconium implant abutments and the torque required to unfasten the retaining screw before and after applying cyclic loading to the implant-abutment assembly. The dynamic behavior and stress distribution pattern of zirconium abutments were also evaluated. Cyclic loading tests were performed via a servohydraulic dynamic testing machine at loads between 100 and 450 N, for up to 5 million loading cycles, at 15 Hz. The dynamic behavior of the zirconium abutments was analyzed by finite element modeling and Pro/Mechanica software, comparing van-der-Mises and maximum stress levels. They concluded that zirconium implant abutments exceeded the established values for maximum incisal bite forces reported in the literature and tightly fit into the titanium implant after several millions of loading cycles.

Vigolo P et al (2006)[53] assessed the rotational freedom between the hexagonal extension of the implant and hexagonal counterpart of the abutment for Procera abutments made with different type of materials (titanium, zirconia and alumina). The results of the study suggested that all types of CAD/CAM Procera abutments consistently showed less than 3 degrees of rotational freedom between the implant and abutment in case of hexagonal external connection.

Barbosa GAS et al (2008)[6] investigated whether there is a direct correlation between the level of vertical misfit at the abutment/implant interface and torque losses in abutment screws. They concluded that there was no significant correlation between the values of vertical misfit at the implant/abutment interface and the values of torque losses applied over the UCLA abutment screws. These findings indicate that great vertical misfits do not necessarily imply higher detorque values.

Stuker RA et al (2008)[47] compared the preload of three types of screw for transmucosal abutment attachment used in single implant-supported prosthesis through strain gauge and removal torque measurements. Three external hex fixtures were used, and each received a transmucosal abutment (Cera One), which was fixed to the implant. They were maintained in position for 5 minutes. After this, the preload values were measured using strain gauges and a measurement cell. They concluded that gold screws may be indicated to achieve superior longevity of the abutment-implant connection and, consequently, prosthetic restoration due to greater preload values yielded.

Theoharidou et al (2008)[49] observed and compared any loosening of screws attaching several interchangeable abutments to internally connected implants after cyclic loading. Four different abutment groups mated with straumann single-stage transmucosal implants were assessed. Abutments were tightened to 35Ncm with a torque controller. A cyclic load of 150 N at a 30-degree angle to the long axis was applied for 1 million cycles. They concluded that although different abutments are interchangeable with each other, they possess different chemical compositions and physical characteristics. Periotest values were measured prior to loading. After cyclic loading, PTVs were measured and removal torque values were measured with digital torque gauge.

Lavrentiadis G et al (2009)[31] correlated the changes in screw length and diameter with previously reported loss of screw tightness. They loaded the samples with a 200N force for 1X 10^6 cycles and measured the reverse torque values, shank length and diameter of the abutment screws. They concluded that for both internal connection and external hexed systems, loss of screw tightness can be correlated with plastic deformation of the screw and the same does not hold true for a conical interface implant system.

Tsuge T et al (2009)[50] evaluated the effect of eccentric cyclic loading on abutment screw loosening in internal and external hexagon implants with titanium (Ti) alloy and gold alloy. The reverse torque value of the abutment screw was measured before (initial preload) and after loading (post-loading). They concluded that the implant-abutment connection did not have an effect, but the abutment screw material did. In particular, Ti abutment screws were less likely to come loose.

Baixe S et al (2010)[5] evaluated the microgap between different zirconia abutments and their titanium implants. Four systems were evaluated. Five assemblies were assessed for each system. The assemblies were embedded in epoxy, cut along their long axes, and polished. Scanning electron microscopic observations were made along the first 100 microm of the gap on each side and Images were combined and gap measurements were made 10 micron apart. They concluded that the mean microgap observed for all tested systems was less than 2 micron and for each system, the microgap decreased quickly from the outer region to the inner. Also, the mean gap was larger for flat-to-flat connection systems, compared to internal-connection systems with a conical interface.

Gomes AL et al (2010)[18] gave a review on ceramic abutments, specifically on zirconia. They made a search of articles of peer-reviewed Journals in PubMed/Medline, crossing the terms "Dental Abutments", "Dental Porcelain" and "Zirconia". The review was divided by subtopics: zirconia physical and mechanical properties, precision fit in the implant-abutment interface, zirconia abutments strength and, finally, bacterial adherence and tissues response. They concluded that zirconia abutments offer good results at all the levels but relevant issues needed further studies and evaluation. One of the most important is the clinical long term success of zirconia abutments on implants, given that in the literature there are no sufficient in-vivo studies that prove it.

Keenam et al (2010)[26] reviewed the performance of ceramic and metal implant abutments from various data sources. A total of 29 studies providing information on the clinical performance of the implant abutments were included in the analysis. They concluded that annual failure rates appeared to be similar for ceramic and metal abutments although the information for ceramic abutments was limited to the number of studies and abutments analysed.

Nigro F et al (2010)[35] verified whether screw abutment lubrication can generate higher preload values compared to non-lubricated screws. Brånemark implants were clamped to a precision torque device, and the abutments were distributed in dry and wet groups with 10 specimens each. In the wet groups, the inner threads of the implants were filled with artificial saliva. Ten detorque measurements were performed per group. The mean detorque values were calculated. The wet condition presented significantly higher means detorque than the dry condition. They concluded that better preload values were established in the wet group, suggesting that the abutment screw must be lubricated in saliva to avoid further loosening.

Ha CY et al (2011)[21] compared the removal torque values (RTVs) of different abutments (straight, angled, and gold premachined UCLA-type) in external- and internal-hex implants after dynamic cyclic loading with the clinical situation of the anterior maxilla simulated. They concluded that there are significant differences in RTVs among different abutment groups in external-hex implants but not in internal-hex implants.

Klotz MW et al (2011)[30] used clinical simulation to determine whether wear of the internal surface of a titanium implant was greater following connection and loading of a one-piece zirconia implant abutment or a titanium implant abutment. They concluded that the implants with the zirconia abutments showed a greater initial rate of wear and more total wear than the implants with the titanium abutments following cyclic loading. The amount of titanium transfer seen on the zirconia abutment increased with the number of loading cycles but appeared to be self-limiting. The clinical ramifications of this finding are unknown at this time; however, the potential for component loosening and subsequent fracture and/or the release of particulate titanium debris may be of concern.

Kanchanapoomi T et al (2011)[24] compared the effect of 3 screw tightening methods on screw loosening resistance for the implants. The abutment screws were tightened to the torque of 35 N-cm to connect the implants and abutments with the 3 tightening methods. The fatigue loading (60N) was applied for 106 times. The reverse torque values were measured by the torque gauge. The screw loosening resistance was expressed as the reverse torque value in the percentage of initial tightening torque. They suggested the importance of the screw retightening method after 10 minutes.

Kim SK et al (2012)[29] observed and compared any loosening of screws attaching several interchangeable abutments to internally connected implants after cyclic loading. Four different abutment groups mated with Straumann single-stage transmucosal implants were assessed. Each implant was fixed rigidly in a special holding jig. Abutments were tightened to 35 Ncm with a torque controller. A cyclic load of 150 N at a 30-degree angle to the long axis was applied to the implants for 1 million cycles. Prior to loading, Periotest values (PTVs) were measured. After cyclic loading, PTVs were measured and removal torque values (RTVs) of abutments were measured with a digital torque gauge. They concluded that although different abutments are interchangeable with each other, they possess different chemical compositions and physical characteristics. The use of an abutment and implant manufactured by the same company is recommended to prevent the loosening of the abutment screw.

Leutert CR et al (2012)[32] examined the bending moments and fracture patterns of different zirconia abutments with internal implant-abutment connections after static loading and compared their bending moments to those of internally connected titanium abutments. Static loading was applied at a 30-degree angle to the palatal surface until failure, and bending moments were calculated. The type of failure was characterized visually by dismounting the abutments and by examination of cross-sections of the embedded specimens. They concluded that, both the abutment material and the implant-abutment connection design affected the bending moments of abutments after static loading and also internally connected zirconia abutments with horizontal mismatch to the implant exhibited significantly higher bending moments compared to those without horizontal mismatch.

MATERIALS AND METHODS

The present in vitro study was conducted to comparatively evaluate the effect of cyclic loading on the reverse torque values of abutment screws for premachined titanium and zirconia abutments using a digital torque meter.

The following materials and equipments were used for the study:

MATERIALS EMPLOYED:

- Titanium dental implant, standard platform, internal hexagon, 3.75mm diameter, 11.5mm length (ADIN Dental Implants., Israel) (Fig.1)
- Spirit level indicators (Jinhua Hengda Tools, China) (Fig.2)
- Clear autopolymerizing acrylic resin (RR Cold Cure, DPI, India) (Fig.3)
- Premachined titanium esthetic abutment, standard platform, internal hexagon (ADIN Dental Implants., Israel) (Fig.4a)
- Premachined zirconia esthetic abutment , standard platform, internal hexagon (ADIN Dental Implants., Israel) (Fig.4b)
- Titanium abutment screw of premachined titanium abutment (Fig.5a)
- Titanium abutment screw of premachined zirconia abutment (Fig.5b)
- Hex driver (ADIN Dental Implants., Israel) (Fig.6)
- Fast curing epoxy compound (Mseal , Pidilite Indistries Ltd., India) (Fig.7)
- Polyvinyl Siloxane (PVS) impression material – Addition type (Aquasil, Dentsply, Germany)
    - ❖ Soft putty/ Regular set (Fig.8a)

- ❖ Light body consistency (Fig 8b)

- Auto mixing spiral (Yellow-70 mm, Adenta, USA) (Fig. 8c)
- Auto mixing gun (Dispensing Gun 2, Heraeus Kulzer, Dormagen, Switzerland) (Fig.8d)
- Die lubricant (Yeti Dental, Germany) (Fig.9)
- Inlay casting wax (GC Corporation, Tokyo, Japan) (Fig.10)
- PKT instruments (Delta labs, Chennai, India) (Fig.11)
- Sprue wax (Bego, Germany) (Fig.12a)
- Surfactant spray (Aurofilm, Bego, Germany) (Fig.12b)
- Silicone investment ring and crucible former (Sili Ring, Delta labs, Chennai, India) (Fig.12c)
- Phosphate bonded investment material (Bellasun, Bego, Germany) (Fig.12d)
- Colloidal silica (Begosol, Bego, Germany) (Fig.12e)
- Carborundum separating discs (Dentorium, New York, U.S.A.) (Fig.12f)
- Ni-Cr alloy pellets (Bellabond plus, Bego, Germany) (Fig.12g)
- Aluminum oxide powder, 100 μm (Delta labs, Chennai, India) (Fig.13)
- Tungsten carbide burs (Edenta, Switzerland) (Fig.14a)
- Silicon carbide rubber points (Dentsply, Germany) (Fig.14b)
- Resin-modified glass ionomer cement (RelyX luting 2, 3M ESPE AG, Seefeld, Germany) (Fig.15)
- Agate plastic spatula (GC Corporation, Tokyo, Japan) (Fig.16a)

- Plastic instrument (API, Manipal, India) (Fig.16b)
- Hand scaler, anterior (API, Manipal, India) (Fig.16c)
- Mixing pad (GC Corporation, Tokyo, Japan) (Fig.16d)

EQUIPMENTS EMPLOYED:

- Dental surveyor (Saeshin Precision Ind. Co., Korea) (Fig.17)
- Vaccum power mixer (Whipmix, Kentucky, U.S.A.) (Fig.18)
- Burnout furnace (Technico, Technico laboratory products Pvt Ltd., Chennai, India) (Fig.19a)
- Induction casting machine (Fornax, Bego, Germany) (Fig.19b)
- Sandblaster (Delta labs, Chennai, India) (Fig.20)
- Alloy grinder (Demco, California, U.S.A.) (Fig.21)
- Digital torque meter (Screw Torque Checker, Model STC50CN, Tonichi Corporation, Tokyo,JAPAN) (Fig.22 a,b,c)
- Line diagram of digital torque meter (Fig.23)
- Custom-made cyclic loading machine (Designed & Manufactured by Lokesh Industries , Chennai) (Fig.24a)
- Line diagram of cyclic loading machine (Fig.24b)
- Custom made positioning Jig (Fig.25)

Description of the Digital Torque Meter (Fig.22 & 23)

In this study, a digital-type torque meter (Screw Torque Checker, Model STC50CN, Tonichi Coporation, and JAPAN) was used. This device is shaped like a screw driver and is suitable for easy and accurate measurements in various inspection and tightening applications (ratchet function). The wireless digital torque driver has a built in digital display which eliminates personal error. This device has the capacity to record from 10 to 50 Ncm. It has a high accuracy level of 0.05 Ncm, which helps to detect even small changes in torque values and has an inbuilt memory to store upto 100 readings and the stored data can be transferred to another storage device via a USB cable. The stored data is not deleted even if the power is turned off since it has an auto memory function from 0.5 to 5.0 seconds. It has an auto-power off function after 3 mins. The above model was chosen based on its user-friendly design.

Description of the custom-made cyclic loading machine: (Fig.24)

In the present study, a cyclic loading machine was custom-fabricated to simulate the components in function, which permitted analysis of possible interaction between the reverse torque value and loading. It consisted of a motor with gearbox, which when rotated, compressed a spring. The spring applied a load, which was transmitted to the test sample. The individual components and the calibration are described below:

Specification of motor:

90 watts, Single phase 230V, Continuous rating, motor giving 1350 RPM with gear reduction box of 1:18 giving a final RPM of 75 (Swipe Industries, Pune, India).

Specification of spring:

Spring load spring ISO 10243:2010 (Special Springs, Rosa, Italy)

Hole diameter – 16 mm, Rod diameter – 8 mm

Free Length of spring – 38 mm

Spring constant – 48.5 N/mm

Specification of timer:

999 minutes timer with time memory (K-Pas, Chennai, India)

The motor was connected to an eccentric cam of 2.5 mm, which rotated when the motor was turned on. The 2.5 mm eccentric cam compressed a spring to the same length as it rotated generating a load of approximately 120 N. The spring transmitted the load to the stylus (3 mm diameter), which transmitted a lesser load of approximately 109 N to the sample due to energy loss.

Calibration of custom-made cyclic loading device:

The maximum and minimum loads delivered by the custom-made cyclic loading device were calibrated by a professional load calibration agency (Hi Tech Calibration Services, Chennai, India).

Calibrated Results:

Auto mode	:	Max. Load: 109.49 N,	Min. Load: -6.52 N
Manual mode	:	Max. Load: 117.83 N,	Min. Load: -7.97 N

Description of Custom- made Jig: (Fig.25)

The custom-made jig consists of a platform and bolt. The sample when placed in the jig platform is positioned at 30° angulation to the platform and can be secured in place with the help of a bolt.

METHODOLOGY:

The methodology adopted in the present study is described under the following sections:

I. Preparation of stainless steel blocks
II. Placement of implants in the stainless steel blocks
III. Connection of abutments to implants
IV. Measurement of the reverse torque value before cyclic loading
V. Retorquing of the abutment screw
VI. Fabrication of Ni-Cr cement-cum-screw retained cast crowns
   a. Preparation of wax patterns
   b. Spruing the wax patterns
   c. Investing the wax patterns
   d. Burnout procedure

e. Casting procedure

f. Divesting and finishing the cast crowns

VII. Cementation of Ni-Cr cast crowns

VIII. Cyclic loading of the test samples

IX. Measurement of the reverse torque values after cyclic loading

X. Data tabulation and statistical analysis

I. Preparation of stainless steel blocks : (Fig. 26)

Twenty (20) stainless steel blocks of dimensions 25mm x 25mm x18mm with a cylindrical mold space of diameter 18mm and depth 16mm were custom-fabricated (Fig.26b). Grooves were made in the internal surfaces of the cylindrical mold space to help retain the autopolymerizing acrylic resin.

II. Placement of implants in the stainless steel blocks : (Fig. 27 - 29)

One custom-made stainless steel block was placed at a time on the surveying platform with the mold space facing up and stabilized. The surveying platform of a dental surveyor (Saeshin Precision Ind. Co., Korea) was made parallel to the floor using spirit level indicators (Fig.27). In the present study, titanium implants (ADIN Dental Implants, Israel) of 3.75mm diameter with standard platform and 11.5mm length and an internal hexagon design were employed. One implant was positioned in the center of mold space of one custom-made metal block such that the implant was submerged completely in the mold space, except for 1 mm at the crest module (Fig.28).

Autopolymerizing clear acrylic resin (Cold Cure, DPI, India) was mixed as per the manufacturer's recommendations and poured into the mold space and then allowed to polymerize. This procedure was repeated to obtain 20 stainless steel blocks with one implant secured in each block (Fig.29).These were randomly divided into two groups of ten each (Group I & Group II).

III. Connection of abutments to implants : (Fig. 30-32)

In the present study, 10 premachined titanium esthetic abutments (ADIN Dental Implants) and 10 premachined zirconia esthetic abutments (ADIN Dental Implants) were used.

In Group I, each of the ten premachined titanium esthetic abutments (n=10) were randomly selected and connected to one embedded implant each with a hex driver (ADIN Dental Implants Technologies, Israel) (Fig.30a).To ensure accurate delivery of torque, the hex driver was secured to the adaptor of the digital torque meter using fast curing epoxy compound (Mseal , Pidilite Indistries Ltd., India) (Fig.31a). The torque gauge was held firm, carefully oriented in the long axis of the implant with the driver seated in the screw head and rotated clockwise until the abutment screw was tightened to 35 Ncm (Fig.31b). A ten minute settling time was allowed, following which they were retightened to 35Ncm to minimize embedment relaxation between the mating threads and thus to assist in achieving the optimal "preload". Thus each titanium abutment was securely connected to the implant (Fig.32a). It was repeated for all twenty samples. The samples were then randomly labeled as T1 to T10. In Group II, each of the ten premachined zirconia esthetic abutments (n=10) were randomly selected and connected to one embedded implant each (Fig.31b) in a similar manner as described above for premachined titanium abutments (Fig.32b). The samples were then randomly labeled as Z1 to Z10.

IV. Measurement of the reverse torque values before cyclic loading: (Fig.33)

After a waiting period of five minutes, for the Group I samples (T1 to T10), the reverse torque value was measured with the digital torque meter and designated as the pre-cyclic loading reverse torque value (pre-RTV_1). Similarly for the Group II samples (Z1 to Z10), the reverse torque value was measured in the similar manner and designated as the pre-cyclic loading reverse torque value (pre-RTV_2) (Fig.33).

V. Retorquing of the abutment screw: (Fig.34)

Subsequent to the pre-RTV_1 measurements, all 10 Group I samples (T1 to T10) were torqued to 35Ncm and then retorqued after a waiting period of 10 mins as described previously to ensure optimal preload prior to cyclic loading (Fig.34)**.** The same procedure was followed for all ten Group II samples (Z1 to Z10)

VI. Fabrication of Ni-Cr cement-cum-screw retained cast crowns: (Fig. 34-41)

a) Preparation of wax patterns : (Fig.35-37)

The wax patterns were designed to obtain cement-cum-screw retained Ni-Cr single crowns for each of the twenty samples. The screw access hole of the abutment was initially filled and sealed off with polyvinyl siloxane putty (Aquasil soft putty, Denstply, Germany) (Fig.35a). The abutment was coated with die lubricant (Yeti Dental, Germany) and excess lubricant was removed using a gentle stream of compressed air. Wax-up was done with inlay casting wax (GC Corporation, Tokyo, Japan) to obtain a single unit crown resembling a maxillary central incisor (Fig.35b). The cingulum area was contoured to create a flat surface at a 30 degree inclination to the long axis of the tooth. After the wax pattern fabrication, abutment screw access channel was kept open to facilitate access to the screw (Fig.35c). Polyvinyl siloxane impression material (Aquasil, Denstply, Germany) light body material is injected over the wax pattern and later soft puty consistency material is adapted over it to obtain an index (Fig.36,37) and used to fabricate and standardize the wax patterns for all the samples. Twenty similar wax patterns were obtained in this manner for samples T1 to T10 & Z1 to Z10.

b) Spruing the wax patterns :(Fig. 38a)

The wax pattern was sprued with preformed wax sprue (Bego, Germany) of 2.5 mm diameter. The wax sprue was attached to the incisal edge of the pattern and a reservoir was placed 1.5 mm away from the pattern. The pattern was directly sprued to the crucible former of the ringless casting system (Sili Ring, Delta labs, Chennai, India) (Fig.38a). All the 20 wax patterns were sprued in an identical manner.

c) Investing the wax patterns: (Fig. 38b)

All the 20 wax patterns were invested individually using graphite free, phosphate-bonded investment material (Bellasun, Bego, Germany) (Fig12d). A 6 mm distance was provided between the patterns and top of the ring. All patterns were sprayed with surfactant spray (Aurofilm, Bego, Germany), to aid in better wetting of the investment material. As per the manufacturer's recommendation, 160 gm of the phosphate-bonded investment was mixed with 38 ml of investment liquid, which was prepared by missing 30 ml of colloidal silica (Begosol, Bego, Germany) and 8 ml of distilled water in the ratio of 3:1. The investment powder was first hand mixed with a spatula until the entire material was wetted thoroughly followed by vacuum mixing for 30 seconds using vacuum power mixer (Whipmix, Kentucky, U.S.A.). Once the investment was mixed the entire pattern was painted with a thin layer of investment using a small paintbrush. The sili ring was positioned on the crucible former and the remainder of investment was poured and vibrated slowly in to the ring (Fig. 38b). The invested patterns were allowed to bench set for 20 minutes, and the sili ring was removed (Fig.38c).

d) Burnout procedure : (Fig.38d)

All the invested patterns were placed individually in a burnout furnace (Technico, Technico laboratory products Pvt. Ltd., Chennai, India) for pattern elimination (Fig.38d). Investments with the patterns were left in the burnout furnace for a period of three hours. During the first hour, the temperature was raised from room temperature to 380^{o}C; in the second hour, the temperature was raised to 900^{o}C and during the last hour the temperature was sustained at 900^{o}C to accomplish complete burnout of the pattern without any residue. The investment mold was initially placed in the furnace such that the crucible end was in contact with the floor of the furnace for the escape of molten material. The investment mold was reversed later near the end of burnout cycle with the sprue hole facing upward to enable escape of the entrapped gases and also to allow oxygen contact to ensure complete burnout of the wax pattern. The same procedure was followed for all twenty cast crowns.

e) Casting procedure: (Fig.38e)

Casting was accomplished with Ni-Cr alloy (Bellabond plus, Bego, Germany) melted in an induction casting machine (Fornax, Bego, Germany) for all the samples of both test groups (Fig.38e). The casting procedure was performed quickly to prevent heat loss resulting in thermal contraction of the mold. The Ni-Cr alloy was heated sufficiently till the alloy ingot turned to molten state and the crucible was released. The centrifugal force ensured the complete flow of the molten metal into the mold space.

f) Divesting and finishing the cast crowns: (Fig. 39)

Following casting, the hot casting was allowed to cool to room temperature. A knife was used to trim the investment at the bottom end of the ring. It was then broken apart and the remaining investment was slowly removed (Fig.39a). Adherent investment was removed from the casting by air abrasion using 110 µm alumina (Delta labs, Chennai, India) at 80 psi pressure in a sand blasting machine (Delta labs, Chennai, India) (Fig.39b) . Sprue was cut using 0.7 mm thin separating discs (Dentorium, New York, U.S.). The casting was inspected under magnification for casting defects. Casting with irregularities in the internal margin, distorted surfaces were discarded. External surfaces were relieved of all nodules with a round carbide bur. All the 20 cast crowns were finished using metal trimming burs (Edenta, Switzerland) and silicon carbide rubber points, white and grey (Dentsply, Germany) (Fig.39 c,d). Each finished crown was seated on its respective abutment and checked for proper fit and marginal accuracy. This procedure was performed for all the twenty cast crowns.

V. Cementation of Ni-Cr cast crowns : (Fig. 40)

Resin modified glass ionomer cement (RelyX Luting 2, 3M ESPE AG, Seefeld, Germany) , which is available as a two-paste system in clicker-type dispensing unit was used for cementation of the cast crowns to their respective abutments. Before cementing the copings, it was ensured that the screw access hole was sealed off with polyvinyl siloxane impression material (Aquasil soft putty, Dentsply, Germany). Equal amounts of base and catalyst paste were dispensed on a mixing pad by pressing the clicker. Both the pastes were mixed with folding technique using an agate plastic spatula (GC Corporation, Tokyo, Japan) for 30 seconds. The mixed cement was carried to the inner surface of the cast crowns with a plastic instrument and painted on the walls (Fig: 40a). The cast crowns were then seated on their respective abutments and pressed down with finger pressure for 5 minutes until the initial set (Fig: 40b). Excess cement was removed carefully using an anterior hand scaler (API, Manipal, India) without scratching the surface of the abutment or implant. A total of twenty Ni-Cr cast crowns were cemented to twenty individual samples consisting of ten titanium and ten zirconia abutments each connected to their respective embedded implants in the stainless steel blocks. These cemented Ni-Cr cast crowns with their respective titanium and zirconia abutments were labeled as Group I and Group II test samples respectively (Fig:41a,b).

VI. Cyclic loading of the test samples : (Fig. 42)

Before beginning each test, a small amount of grease was used to reduce friction and wear at the loading point. Cyclic loading was performed for all twenty test samples individually, with a custom-made cyclic loading machine to simulate oral loading conditions. The test sample with the cemented cast restoration was placed in a custom-made jig, which positioned and secured the sample at a 30 degree angle to the floor to simulate the direction of forces at the maxillary anterior region. This jig was attached to the cyclic loading machine. The stylus of the cyclic loading machine was placed on the flattened cingulum portion of the central incisor and the test sample was subjected to cyclic loading.(Fig.42) A sinusoidal waveform at 1.25 Hz for load between 0 to 109 N (approximately) simulating human masticatory frequency and loads was applied. This cycle was continued for 42 hrs. (2520mins with a break of 2 hrs. every 21 hrs.) simulating approximately 1,89,000 cycles which is approximately 6 months of function. The cyclic loading was performed in a dry environment. This procedure was repeated for all the twenty samples.

VII. Measurement of the reverse torque values after cyclic loading: (Fig.43)

At the completion of the cyclic loading period, the respective test sample was removed from the custom-made cyclic loading machine. Each sample was subjected to visual and tactile inspection for any deformation, decementation and/or abutment rotation or loosening. The reverse torque value after cyclic loading for Group I and Group II test samples were measured with the digital torque meter and recorded as the post-cyclic loading reverse torque values (post-RTV_1 & post-RTV_2).

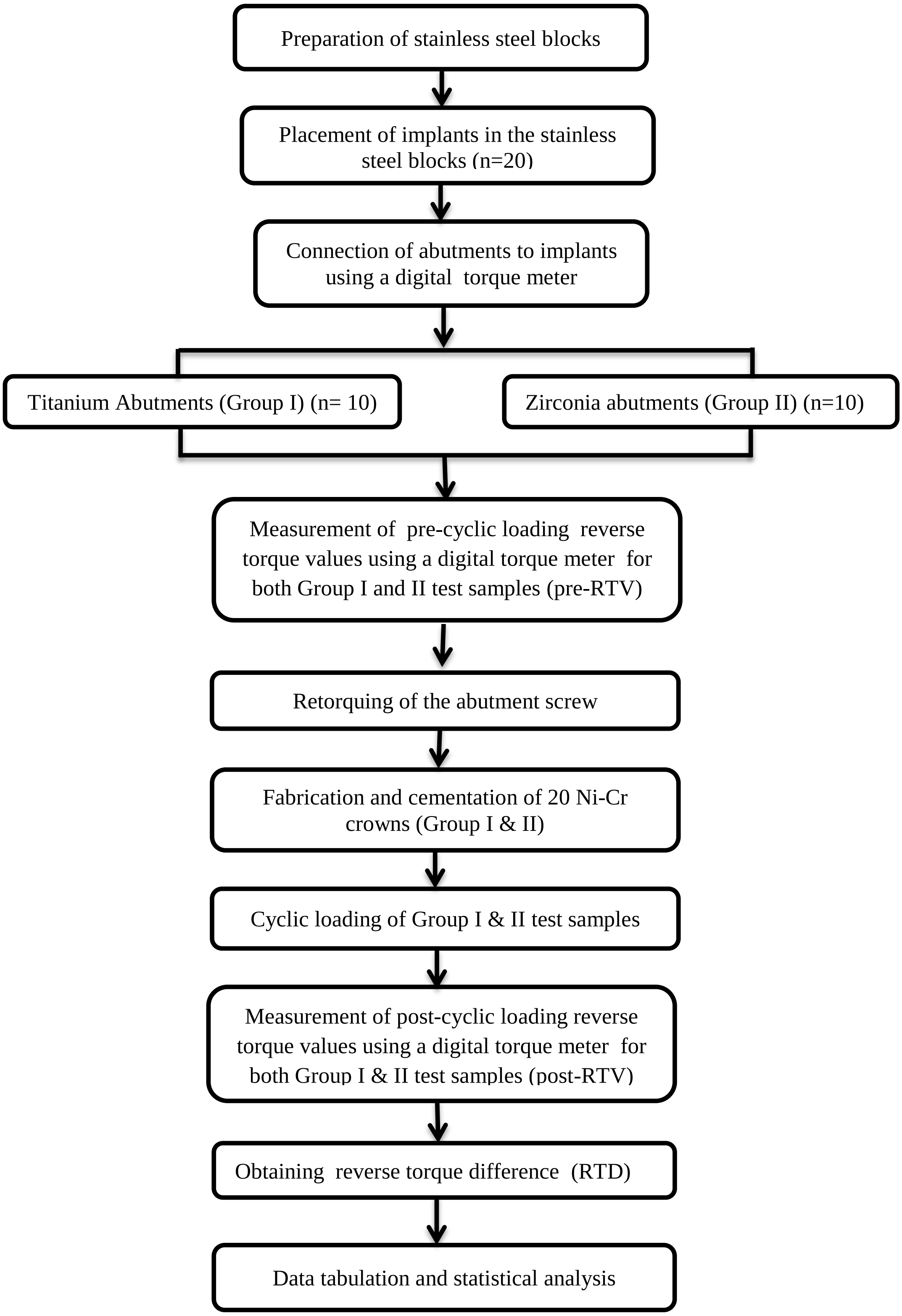
The reverse torque difference (RTD) was calculated by finding the difference between the post-cyclic loading reverse torque value and pre-cyclic loading reverse torque value. (RTD = post- RTV (-) pre- RTV). The data obtained were tabulated and subjected to statistical analysis.

VIII. Data tabulation and statistical analysis:

The data obtained was tabulated and these results were subjected to statistical analysis. All statistical calculations were performed using Microsoft Excel (Microsoft, USA) and SPSS (SPSS for Windows 10.0.5, SPSS Software Corp., Munich, Germany) software.

Paired‘t’-test was used to compare the difference in reverse torque values within both test groups before and after cyclic loading. Independent ‘t’-test was used to compare the respective mean pre-cyclic loading reverse torque values and the respective mean post-cyclic loading reverse torque values for both the test groups.

METHODOLOGY – OVERVIEW



MATERIALS

Fig.1: Titanium dental implant standard platform, 3.75mm

Fig.2: Spirit level indicators

Fig.3: Clear auto polymerizing acrylic resin

a **b**

Fig.4a: Premachined titanium esthetic abutment, standard platform

b: Premachined zirconia esthetic abutment, standard platform

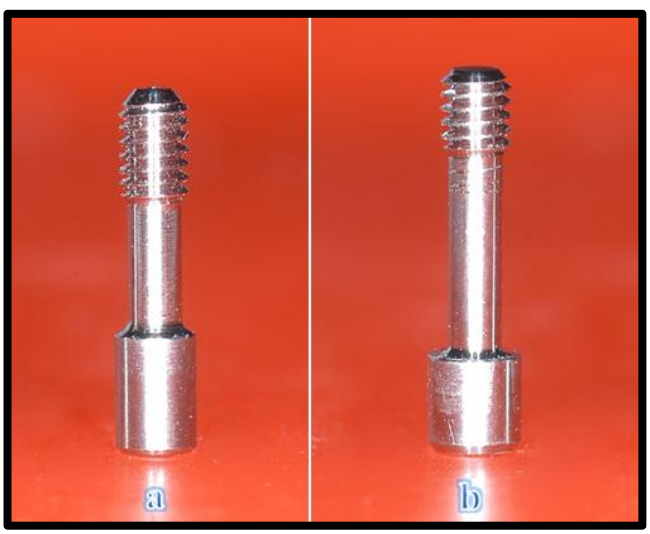


Fig.5a: Titanium abutment screw of premachined titanium abutment

b: Titanium abutment screw of premachined zirconia abutment

Fig.6 : Hex driver

Fig.7: Fast curing epoxy compound

Fig.8a: Soft Putty, Polyvinyl Siloxane (PVS) impression material-Addition type

b: Light Body, Polyvinyl Siloxane (PVS) impression material-Addition type

c: Mixing spiral

d: Automixing gun

Fig.9: Die lubricant

Fig.10: Inlay casting wax

Fig.11: PKT Instruments

Fig.12a: Sprue wax

b: Surfactant spray

c: Investment ring and crucible former

d: Phosphate bonded investment material

e: Colloidal silica

f: Carborundum seperating discs

g: Ni-Cr alloy pellets

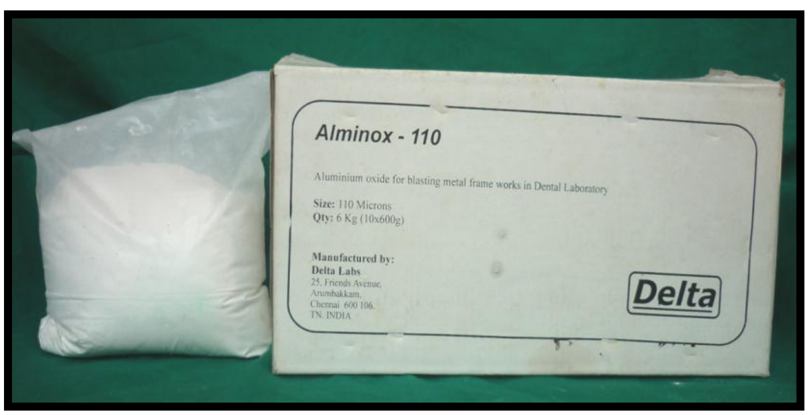


Fig.13: Aluminum oxide powder – 110 µm

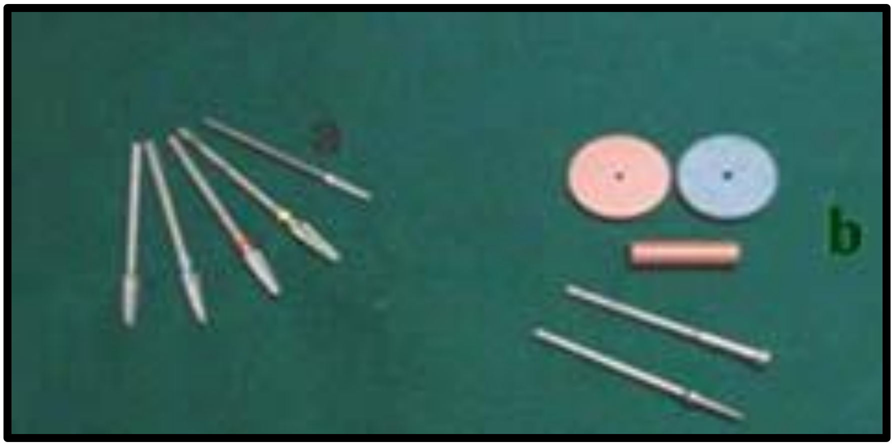


Fig.14a: Tungsten carbide metal trimming burs

b: Silicon carbide rubber point

Fig.15: Resin-modified glass ionomer cement

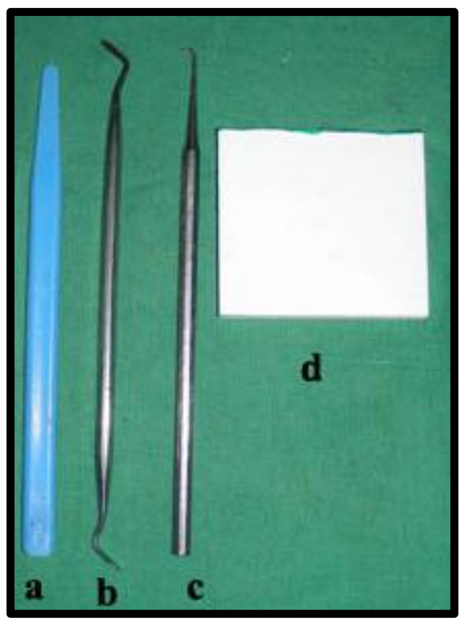


Fig.16a: Agate plastic spatula

b: Plastic instrument

c: Hand scaler

d: Mixing pad

EQUIPMENTS

Fig.17: Dental surveyor

Fig.18: Vacuum power mixer

Fig.19a: Burnout furnace

Fig19b: Induction casting

Fig.20: Sandblaster

Fig.21: Alloy grinder

Fig22a: Digital torque meter

b: Torque meter adaptor for attaching hex driver

c: Interconnecting tool for attaching adaptor to the torque meter

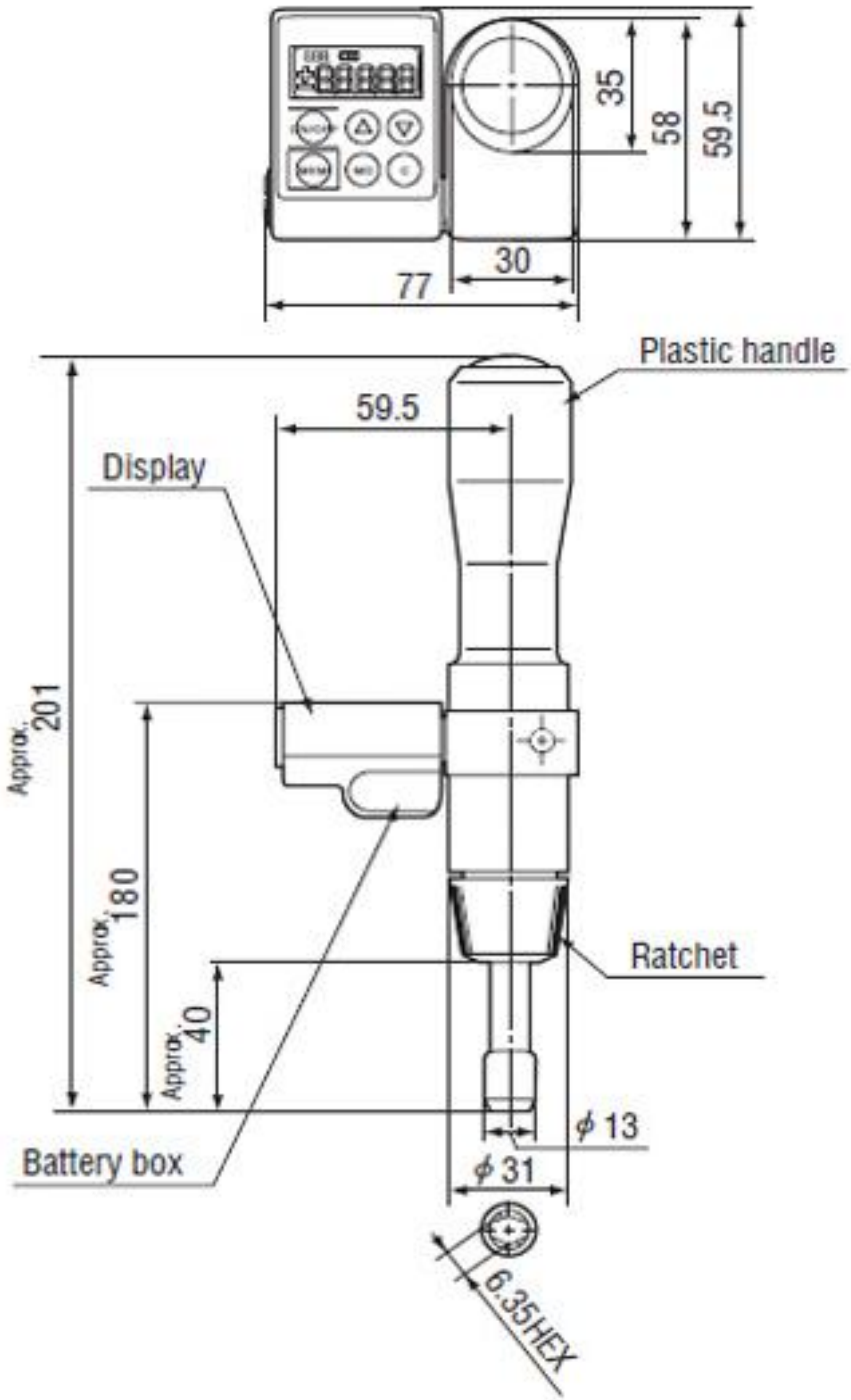


Fig 23: Line diagram of digital torque meter

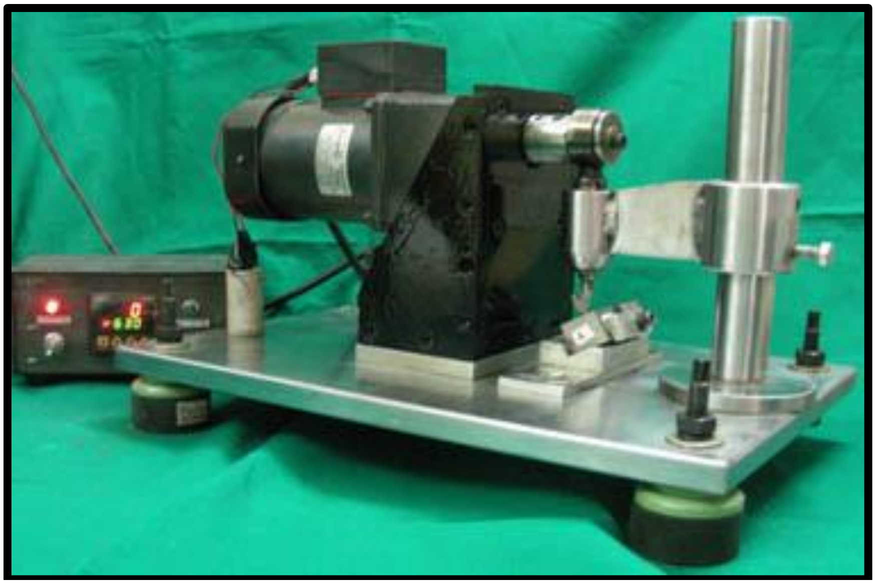


Fig.24a: Custom-made cyclic loading machine

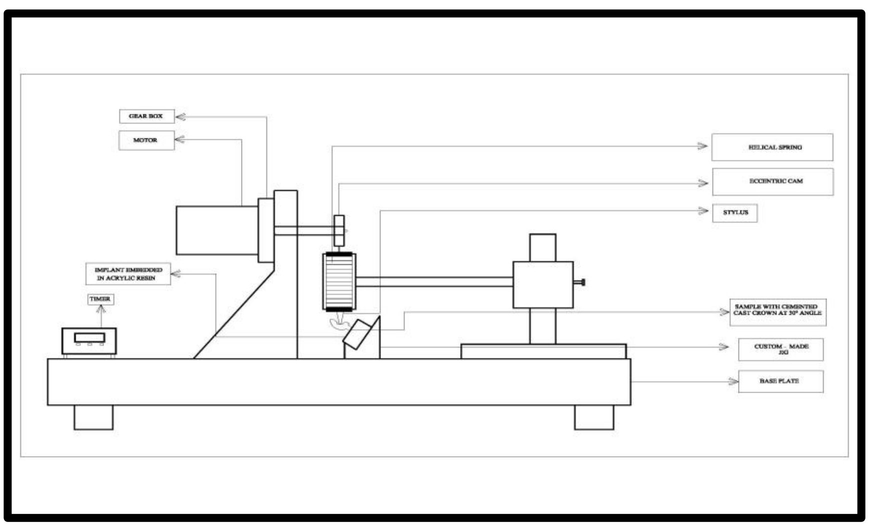
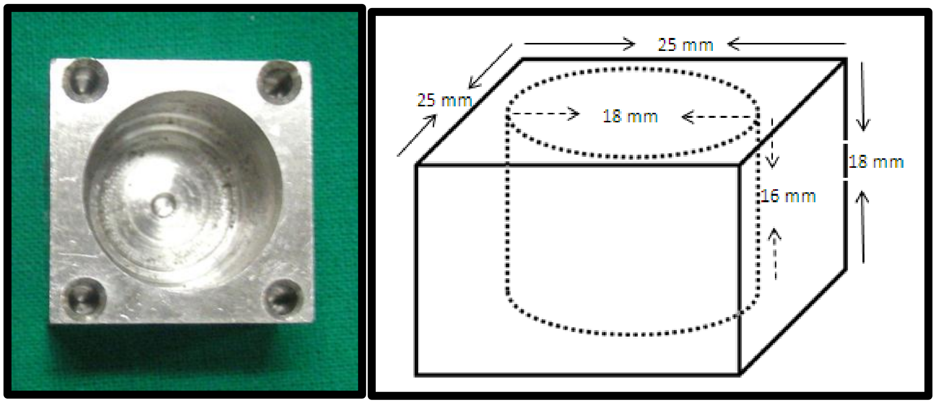


Fig.24b: Line diagram for custom-made cyclic loading maching

Fig.25: Custom-made positioning jig

METHODOLOGY

I.PREPARATION OF STAINLESS STEEL BLOCKS



a **b**

Fig.26a: Custom-made stainless steel block

b: Line diagram of custom-made stainless steel block

II. PLACEMENT OF IMPLANTS IN STAINLESS STEEL BLOCKS

Fig.27:Surveying platform made parallel to floor using spirit level indicators

Fig.28:Positioning of titanium implant in SS block

Fig.29: Implant secured with acrylic resin

III. CONNECTION OF ABUTMENTS TO IMPLANTS

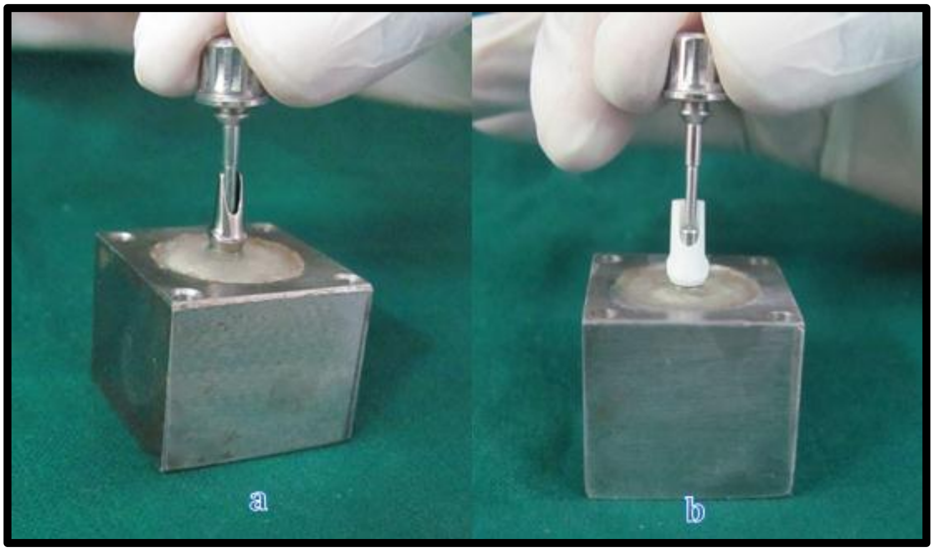


Fig 30a: Connection of premachined titanium abutment to implant using a hex driver
b: Connection of premachined zirconia abutment to implant using a hex driver

Fig.31a: Hex driver secured into the adaptor of digital torque driver

Fig.31b: Torquing of abutment to implant to 35Ncm using digital torque meter

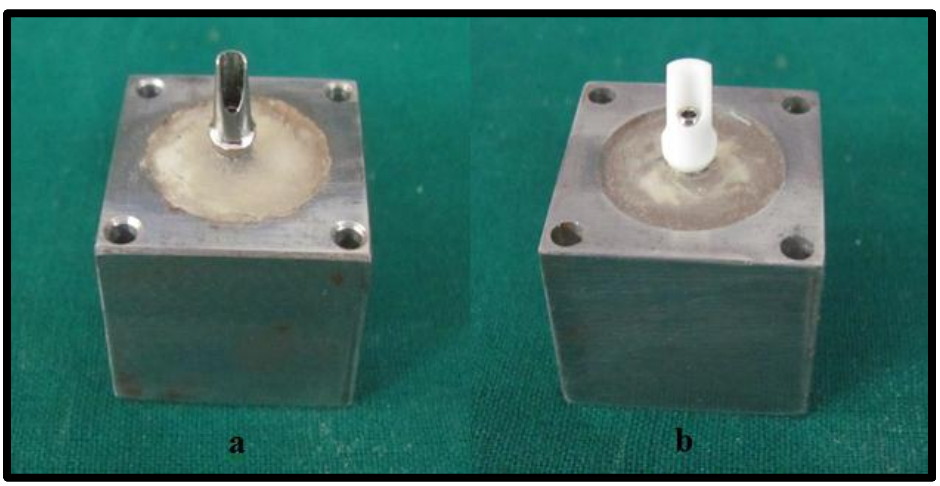


Fig.32a:Premachined titanium abutment connected to implant
b:Premachined zirconia abutment connected to implant

IV. MEASUREMENT OF REVERSE TORQUE VALUE BEFORE CYCLIC LOADING:

Fig 33: Measurement of reverse torque value before cyclic loading

V. RETORQUING OF THE ABUTMENT SCREW

Fig 34: Retorquing of the abutment screw to 35Ncm

VI. FABRICATION OF Ni-Cr CAST CROWNS

Preparation of wax patterns

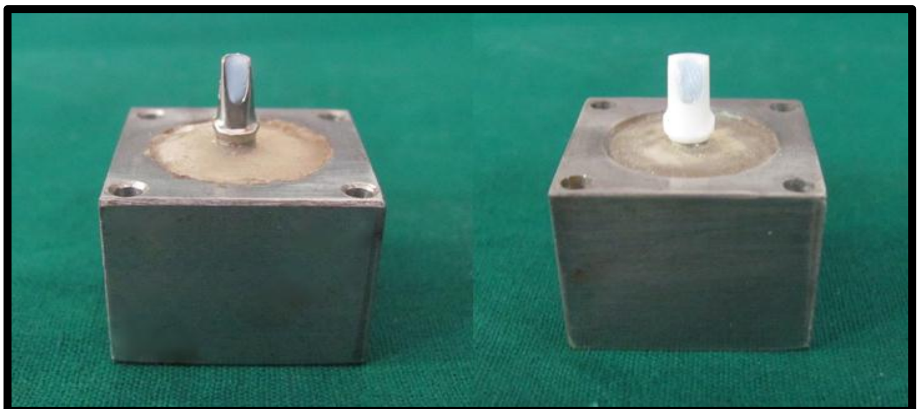


Fig.35a: Sealing of the screw access hole of the abutments with polyvinyl Siloxane putty material

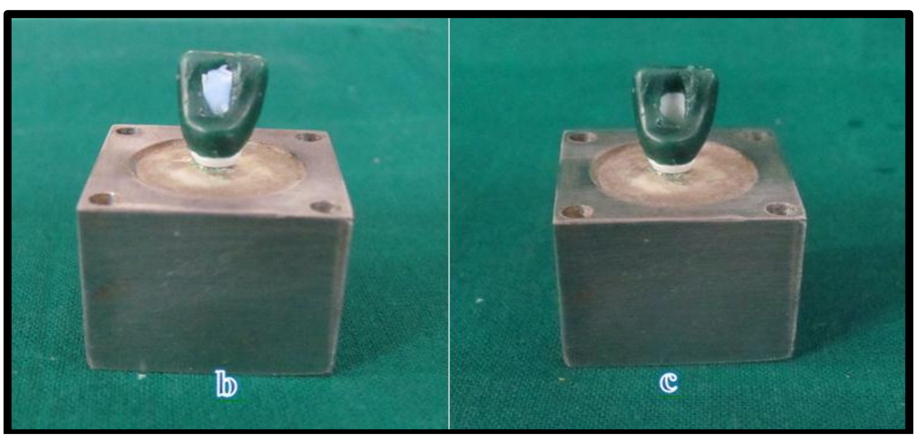


Fig.35b: Wax pattern of central incisor with contoured cingulum area
c: Putty removed from screw access hole

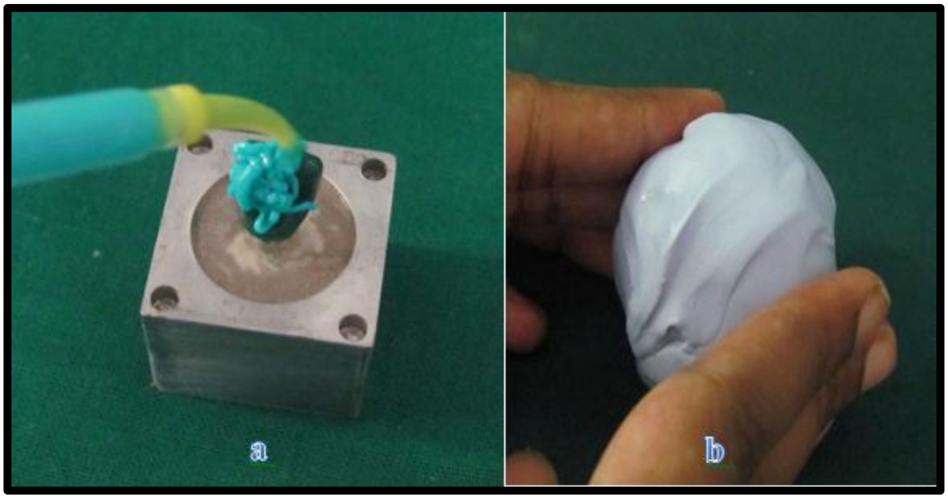


Fig 36a: Polyvinyl Siloxane light body material injected over the wax pattern
b: Polyvinyl Siloxane putty material adapted over the wax pattern

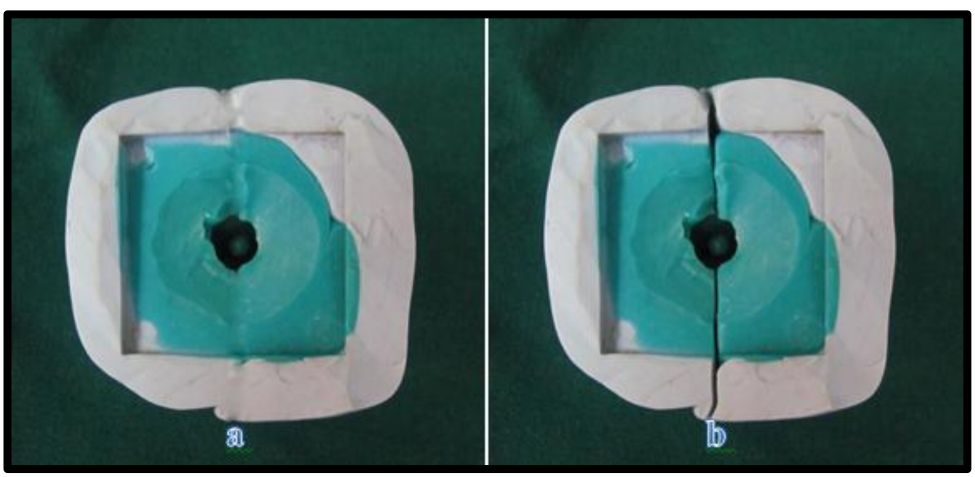


Fig.37a: Completed Index for duplicating the wax patterns
b: Sectioned index for duplicating the wax patterns

SPRUING, INVESTING, BURNOUT,CASTING AND FINISHING OF Ni-Cr CAST CROWNS

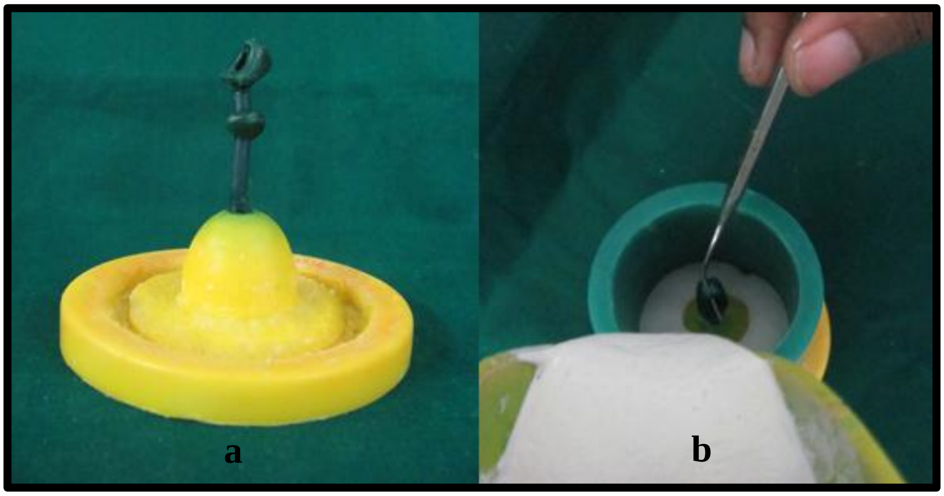


Fig.38a: Spruing of wax pattern
b: Investing the wax pattern

Fig.38c:Invested pattern
d:Invested pattern placed in burnout furnace

Fig.38e: Casting done in induction casting machine

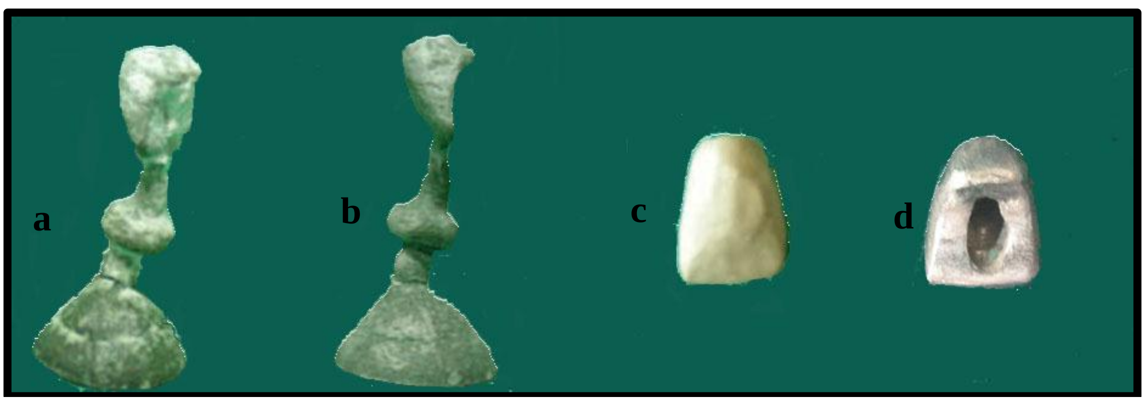


Fig.39a: Divested casting
b: Sandblasted casting
c: Finished crown (labial view)
d: Finished crown (palatal view)

VII. CEMENTATION OF Ni-Cr CAST CROWNS

Fig.40a: Mixed cement loaded into the crown

Fig.40b: Crown seated on the abutment with finger pressure

Fig.41a: Group I test samples (Premachined titanium abutments with cemented cast crowns)

Fig.41b: Group II test samples (Premachined zirconia abutments with cemented cast crowns)

VIII. CYCLIC LOADING OF THE SAMPLE

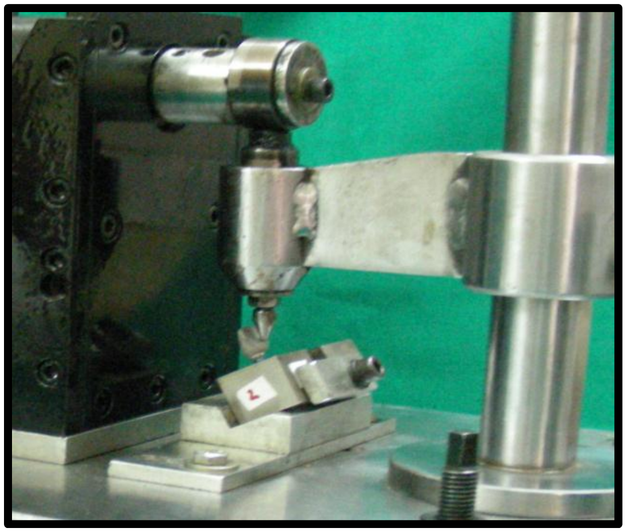


Fig.42: Cyclic loading of test sample

IX. MEASUREMENT OF REVERSE TORQUE VALUE AFTER CYCLIC LOADING

Fig 43: Measurement of reverse torque value after cyclic loading

RESULTS

The present in vitro study was conducted to comparatively evaluate the effect of cyclic loading on the reverse torque values of abutment screws for premachined titanium and zirconia abutments using a digital torque meter.

The reverse torque values obtained for Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples using a digital torque meter were tabulated and subjected to statistical analysis using paired ‘t’test and independent ‘t’test.

Table I shows the basic values and mean pre-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments).

Table II shows the basic values and mean post-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments).

Table III shows the basic values and mean reverse torque difference of Group I test samples (premachined titanium abutments).

Table IV shows the basic values and mean pre-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments).

Table V shows the basic values and mean post-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments).

Table VI shows the basic values and mean reverse torque difference of Group II test samples (premachined zirconia abutments).

Table VII shows the comparative evaluation of the mean pre- and post-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments) using Paired't'-test.

Table VIII shows the comparative evaluation of the mean pre- and post-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments) using Paired 't'-test.

Table IX shows the comparative evaluation of the mean pre-cyclic loading reverse torque values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples using Independent't'-test.

Table X shows the comparative evaluation of the mean post-cyclic loading reverse torque values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples using Independent't'-test.

Table XI shows the comparative evaluation of the mean reverse torque difference of Group I (premachined titanium abutments) and Group II premachined zirconia abutments) test samples using Independent't'-test.

Table XII shows the overall comparison between mean pre- and post cyclic loading reverse torque values and the mean reverse torque difference of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples.

Graph I shows the basic values of pre-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments).

Graph II shows the basic values of post-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments).

Graph III shows the basic values of reverse torque difference of Group I test samples (premachined titanium abutments)

Graph IV shows the basic values of pre-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments).

Graph V shows the basic values of post-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments).

Graph VI shows the basic values of reverse torque difference of Group II test samples (premachined zirconia abutments)

Graph VII shows the comparative evaluation of the mean pre- and post-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments).

Graph VIII shows the comparative evaluation of the mean pre- and post-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments).

Graph IX shows the comparative evaluation of the mean pre-cyclic loading reverse torque values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples.

Graph X shows the comparative evaluation of the mean post-cyclic loading reverse torque values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples.

Graph XI shows the comparative evaluation of the mean reverse torque difference values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples.

Graph XII shows the overall comparison between the mean pre- and post-cyclic loading reverse torque values and the mean reverse torque difference values of Group I (premachined titanium abutments) and Group II test samples (premachined zirconia abutments).

Table I: Basic values and mean pre-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments)

Sample no	Pre- RTV_1 (Ncm)
T1	28.62
T2	27.98
T3	30.09
T4	29.64
T5	29.27
T6	28.62
T7	30.78
T8	31.33
T9	29.46
T10	27.29
Mean/ S.D	**29.3080/ ±1.2376**

Inference:

Maximum pre-RTV_1 = 31.33 Ncm

Minimum pre-RTV_1 = 27.29 Ncm

Mean pre-RTV_1 =29.3080 Ncm

Table II: Basic values and mean post-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments)

Sample no.	Post- RTV_1 (Ncm)
T1	28.12
T2	27.17
T3	29.14
T4	28.82
T5	28.19
T6	27.96
T7	29.85
T8	30.56
T9	28.63
T10	26.52
Mean/ S.D	**28.4960/ ±1.1933**

Inference:

Maximum post-RTV_1 = 30.56 Ncm

Minimum post-RTV_1 = 26.52 Ncm

Mean post-RTV_1 =28.4960 Ncm

Table III: Basic values and mean reverse torque difference of Group I test samples (premachined titanium abutments)

Sample no.	Pre-RTV_1 (Ncm)	Post-RTV_1 (Ncm)	Post-RTV_1(-) Pre-RTV_1 RTD_1 (Ncm)
T1	28.62	28.12	-0.5
T2	27.98	27.17	-0.81
T3	30.09	29.14	-0.95
T4	29.64	28.82	-0.82
T5	29.27	28.19	-1.08
T6	28.62	27.96	-0.66
T7	30.78	29.85	-0.93
T8	31.33	30.56	-0.77
T9	29.46	28.63	-0.83
T10	27.29	26.52	-0.77
Mean/ S.D	**29.3080/ ±1.2376**	**28.4960/ ±1.1933**	**-0.8120 / ±0.1596**

Inference:

Maximum RTD_1 = -1.08Ncm

Minimum RTD_1 = -0.5Ncm

Mean RTD_1 = -0.8120 Ncm

Table IV: Basic shows basic values and mean pre-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments)

Sample no.	**Pre-RTV_2 (Ncm)**
Z1	27.70
Z2	26.42
Z3	28.38
Z4	26.26
Z5	25.81
Z6	25.18
Z7	26.47
Z8	27.08
Z9	25.21
Z10	26.20
Mean/ S.D	**26.4710 / ±1.0187**

Inference:

Maximum pre-RTV_2 = 28.38 Ncm

Minimum pre-RTV_2 = 25.18 Ncm

Mean pre-RTV_2 = 26.4710 Ncm

Table V: Basic values and mean post-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments)

Sample no.	**Post-RTV$_2$ (Ncm)**
Z1	26.73
Z2	25.21
Z3	27.65
Z4	24.62
Z5	24.26
Z6	24.27
Z7	25.39
Z8	26.09
Z9	24.03
Z10	24.67
Mean/ S.D	**25.2920 / ± 1.1936**

Inference:

Maximum post-RTV$_2$ = 27.65 Ncm

Minimum post-RTV$_2$ = 24.03 Ncm

Mean post-RTV$_2$ = 25.2920 Ncm

Table VI: Basic values and mean reverse torque difference of Group II test samples (premachined zirconia abutments)

Sample no.	Pre-RTV_2 (Ncm)	Post-RTV_2 (Ncm)	Post-RTV_2 (-) Pre-RTV_2 RTD_2 (Ncm)
Z1	27.70	26.73	-0.97
Z2	26.42	25.21	-1.21
Z3	28.38	27.65	-0.73
Z4	26.26	24.62	-1.64
Z5	25.81	24.26	-1.55
Z6	25.18	24.27	-0.91
Z7	26.47	25.39	-1.08
Z8	27.08	26.09	-0.99
Z9	25.21	24.03	-1.18
Z10	26.20	24.67	-1.53
Mean/ S.D	**26.4710/ ±1.0187**	**25.2920/ ±1.1936**	**-1.1790 / ±0.3050**

Inference:

Maximum RTD_2 = -1.64 Ncm

Minimum RTD_2 = -0.73 Ncm

Mean RTD_2 = -1.1790 Ncm

Table VII: Comparative evaluation of the mean pre- and post-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments) using Paired'tʼ-test

GROUP I (Titanium)	Number of samples	Mean RTV_1(Ncm)	Mean / S.D RTD_1(Ncm)	p – value
Pre-cyclic loading (pre-RTV_1)	10	29.3080	-0.8120 / ±0.15957	0.000*
Post-cyclic loading (post-RTV_1)	10	28.4960		

*p value < 0.05; significant at 5% level

Inference: On statistical analysis using paired'tʼ-test to compare the mean reverse torque values of Group I test samples before and after cyclic loading, it was found that the mean post-cyclic loading reverse torque value of Group I test samples (post-RTV_1) was lesser than the mean pre-cyclic loading reverse torque value (pre-RTV_1) and the mean difference between the reverse torque values (RTD_1) was found to be statistically significant (p value < 0.05).

Table VIII: Comparative evaluation of the mean pre- and post-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments) using Paired 't'-test

GROUP II (Zirconia)	Number of samples	Mean RTV_2(Ncm)	Mean / S.D RTD_2(Ncm)	p – value
Pre- cyclic loading (pre-RTV_2)	10	26.4710	-0.1790 /±0.30505	0.003*
Post- cyclic loading (post-RTV_2)	10	25.2920		

*p value < 0.05; significant at 5% level

Inference: On statistical analysis using paired't'-test to compare the mean reverse torque values Group II test samples before and after cyclic loading, it was found that the mean post-cyclic loading reverse torque value of Group II test samples (post-RTV_2) was lesser than its mean pre-cyclic loading reverse torque value (pre-RTV_2) and the difference between the reverse torque values (RTD_2) was found to be statistically significant (p value < 0.05).

Table IX: Comparative evaluation of the mean pre-cyclic loading reverse torque values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples using Independent'‘t’-test

GROUP	Number of samples	Mean / S.D Pre-cyclic loading RTV (Ncm)	P – value
I (Titanium)	10	29.3080 / ±1.2376	0.000*
II (Zirconia)	10	26.4710 / ±1.0187	

*p value < 0.05; significant at 5% level

Inference: On statistical analysis using independent ‘t’-test to compare the respective mean pre-cyclic loading reverse torque values of Group I and II samples , it was found that the mean pre-cyclic loading reverse torque value of Group I samples was higher than that of Group II samples and this difference was found to be statistically significant (P value <0.05)

Table X: Comparative evaluation of the mean post-cyclic loading reverse torque values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) II test samples using Independent't'-test

GROUP	Number of samples	Mean / S.D Post-cyclic loading RTV (Ncm)	P – value
I (Titanium)	10	28.4960 / ±1.1933	0.000^{*}
II (Zirconia)	10	25.2920 / ±1.1936	

*P value < 0.05; significant at 5% level

Inference: On statistical analysis using independent 't'-test to compare the respective mean post-cyclic loading reverse torque values of Group I and II samples after cyclic loading, it was found that the mean post-cyclic loading reverse torque value of Group I samples was higher than that of Group II samples and this difference was found to be statistically significant (p value <0.05)

Table XI: Comparative evaluation of the mean reverse torque difference values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples using Independent'‘t’-test

GROUP	Number of samples	Mean / S.D RTD (Ncm)	P – value
I (Titanium)	10	-0.8120 / ±0.1596	0.003*
II (Zirconia)	10	-1.1790 / ±0.3050	

*p value < 0.05; significant at 5% level

Inference: On statistical analysis using independent ‘t’-test to compare the respective mean reverse torque difference of Group I and II , it was found that the mean reverse torque difference of Group I samples was lesser than the mean reverse torque difference of Group II samples and this difference was found to be statistically significant (p value <0.05)

Table XII: Overall comparison between the mean pre- and post-cyclic loading reverse torque values and the mean reverse torque difference values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples

	Group I (Titanium)	**Group II (Zirconia)**	**P-value**
Pre-cyclic loading RTV (Ncm)	29.3080	26.4710	0.000*
Post-cyclic loading RTV (Ncm)	28.4960	25.2920	0.000*
RTD (Ncm)	-0.8120	-1.1790	0.003*
P value	0.000*	0.000*	

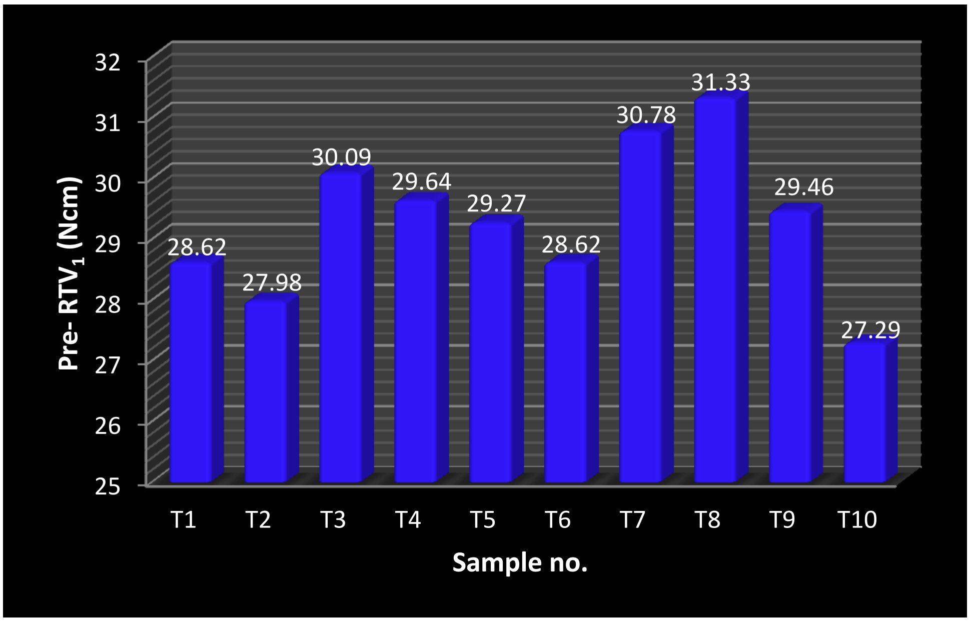
*p value < 0.05; significant at 5% level.

Inference: Statistical analysis with Paired ‘t’-test was used to compare the effects of cyclic loading on mean reverse torque values of Group I and Group II samples. The mean reverse torque values after cyclic loading were lesser than the mean reverse torque values before cyclic loading for both Group I (Titanium) and Group II (Zirconia) samples. There was a statistically significant decrease in the reverse torque values after cyclic loading with Group I (Titanium) and Group II (Zirconia) samples.

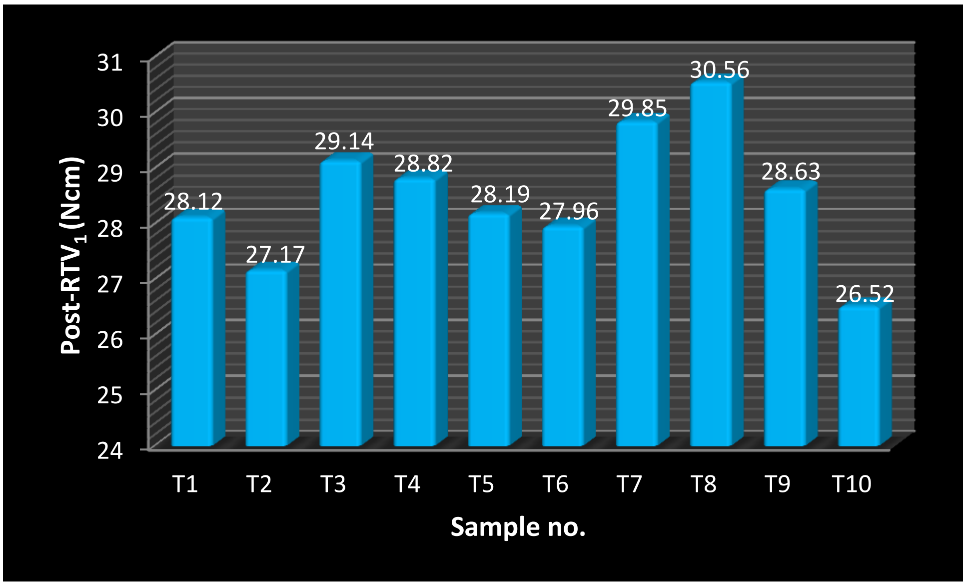
Statistical analysis with Independent‘t’-test was used to compare the mean reverse torque values of Group I and Group II samples before and after cyclic loading. The mean reverse torque value of Group I (Titanium) samples was higher than the mean reverse torque value of Group II (Zirconia) samples, both before and after cyclic loading. There was statistically significant difference between the mean reverse torque values of Group I (Titanium) and Group II (Zirconia) samples, both before and after cyclic loading.

Statistical analysis with independent ‘t’-test was used to compare the mean reverse torque difference of Group I and II, it was found that the mean reverse torque difference of Group I samples was lesser than the mean reverse torque difference of Group II samples and it was statistically significant ($p > 0.05$).

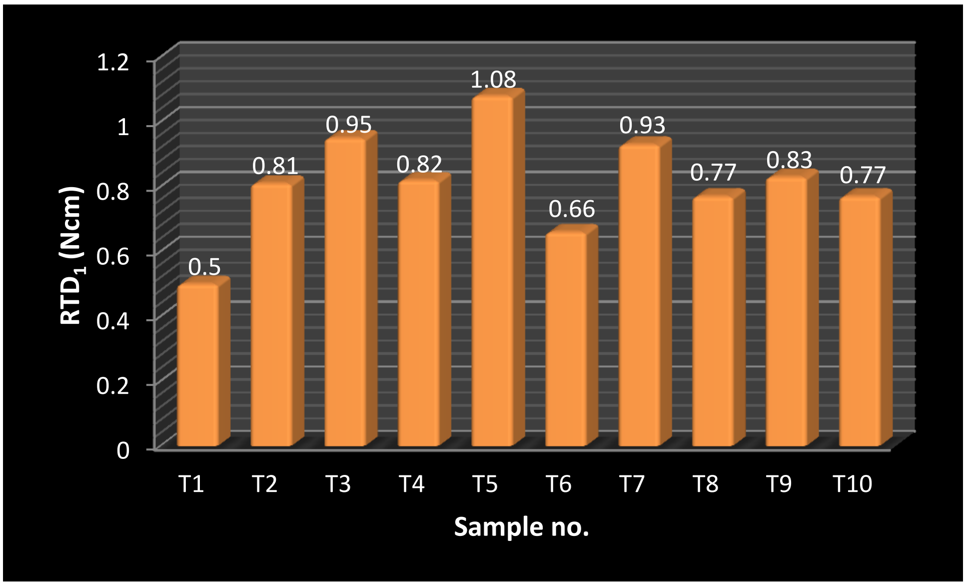
Graph I: Basic Values of pre-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments)



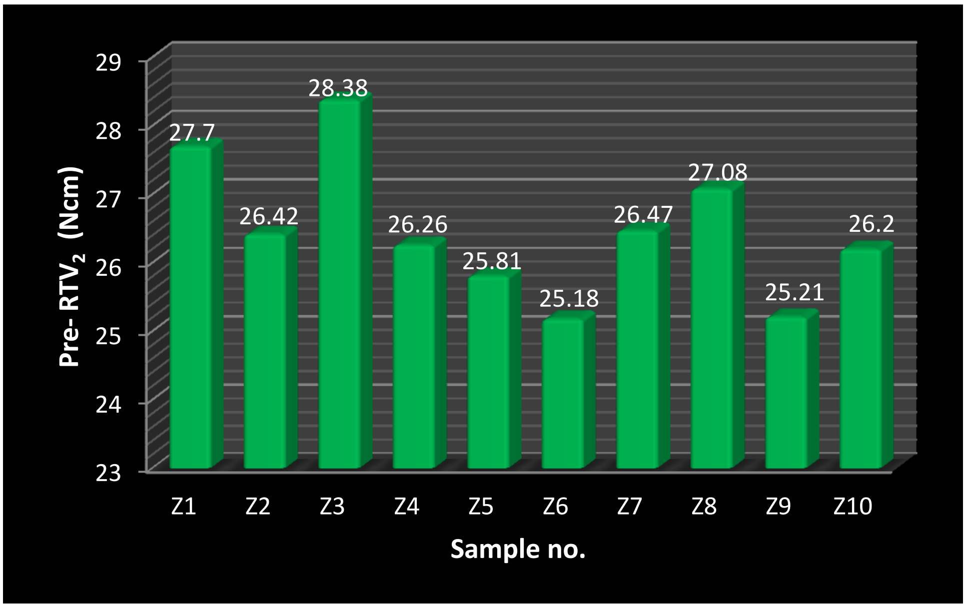
Graph II: Basic Values of post-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments)



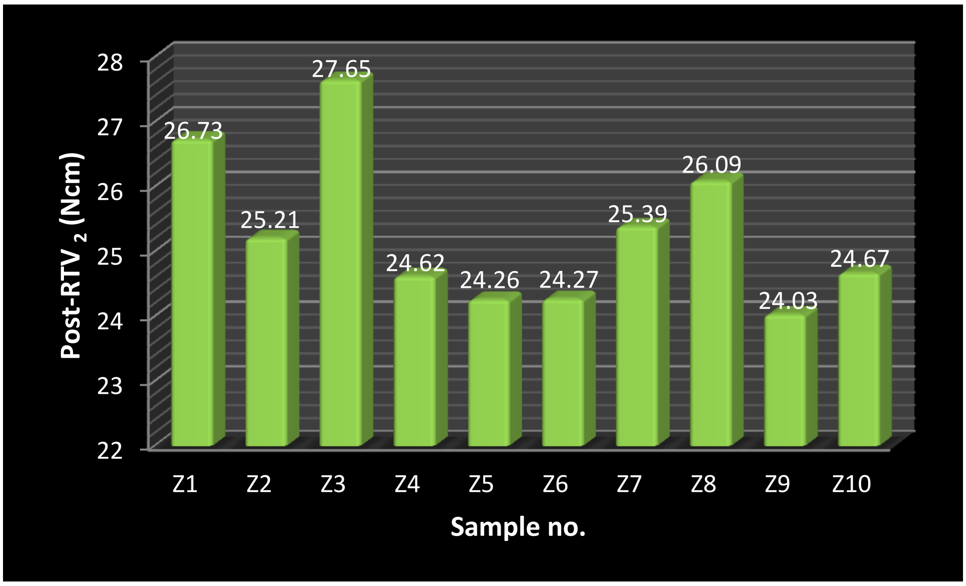
Graph III: Basic Values of the reverse torque difference of Group I test samples (premachined titanium abutments)



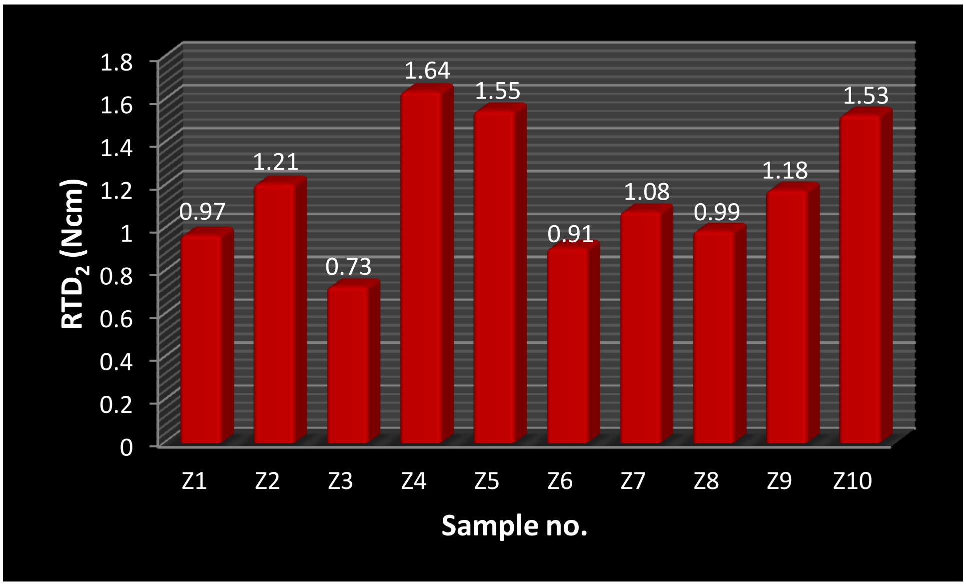
Graph IV: Basic Values of pre-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments)



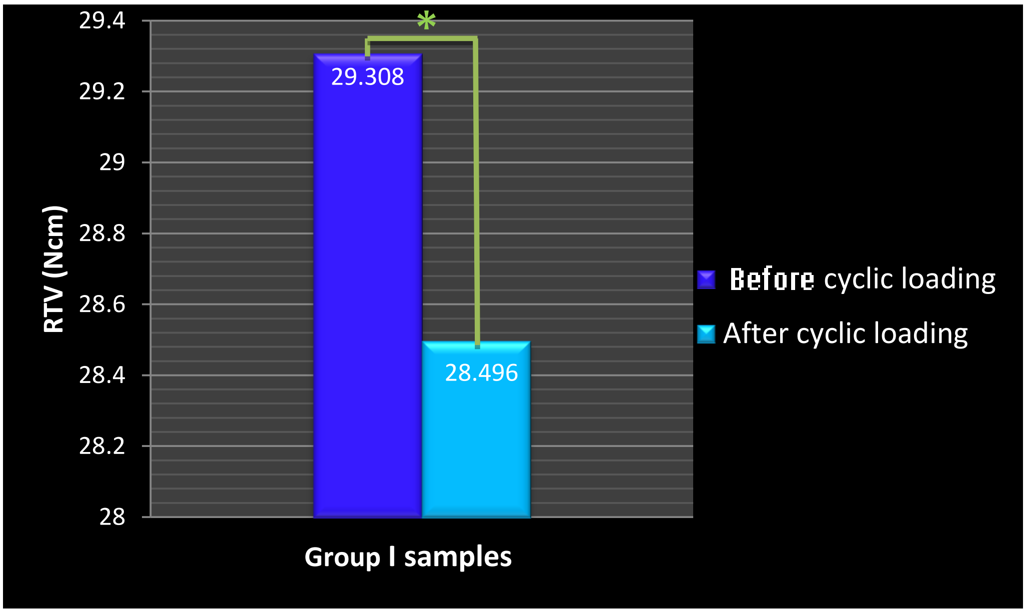
Graph V: Basic Values of post-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments)



Graph VI: Basic Values of the reverse torque difference of Group II test samples (premachined zirconia abutments)

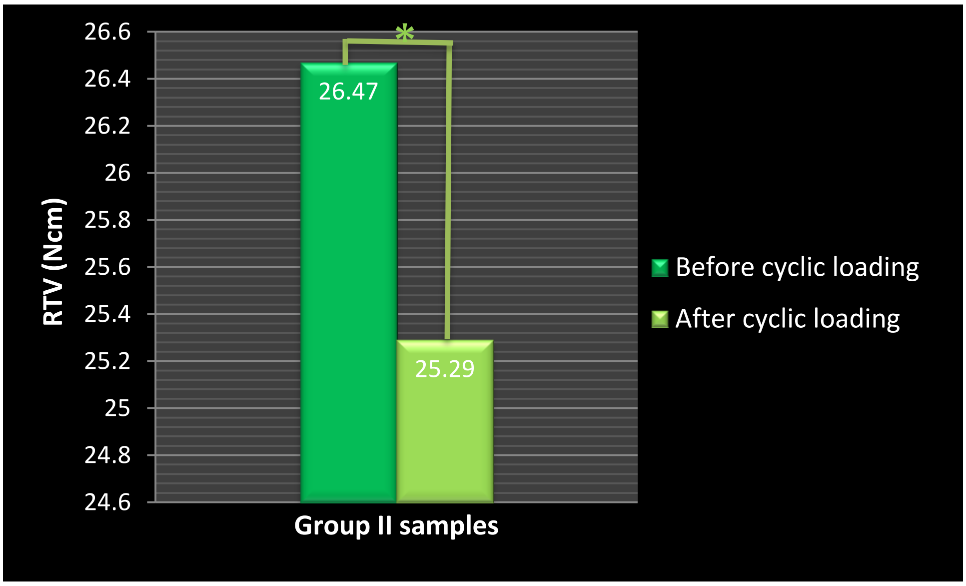


Graph VII: Comparative evaluation of the mean pre- and post-cyclic loading reverse torque values of Group I test samples (premachined titanium abutments)



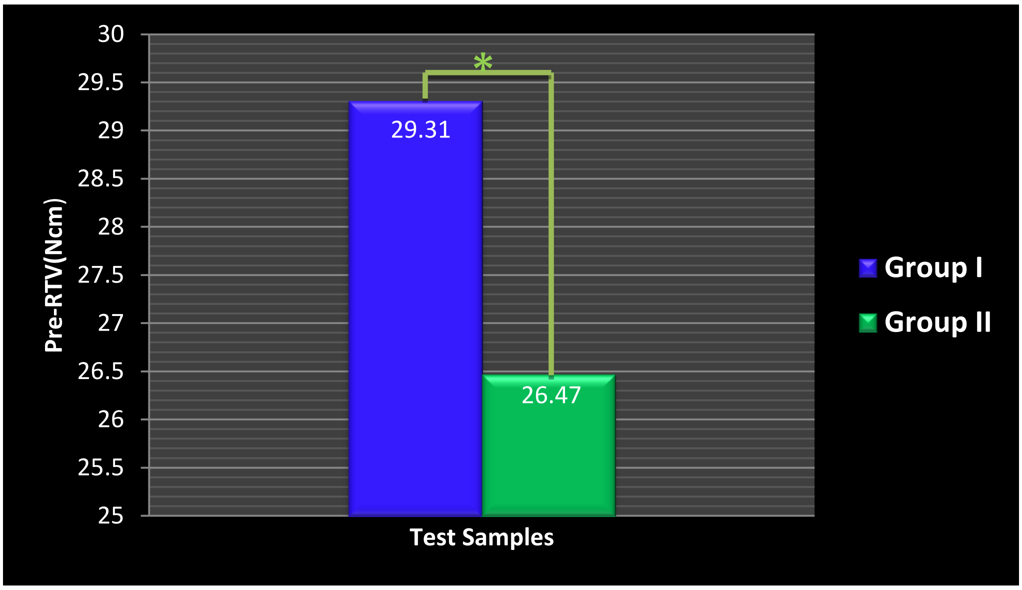
*Significant at 5% level

Graph VIII: Comparative evaluation of the mean pre and post-cyclic loading reverse torque values of Group II test samples (premachined zirconia abutments)



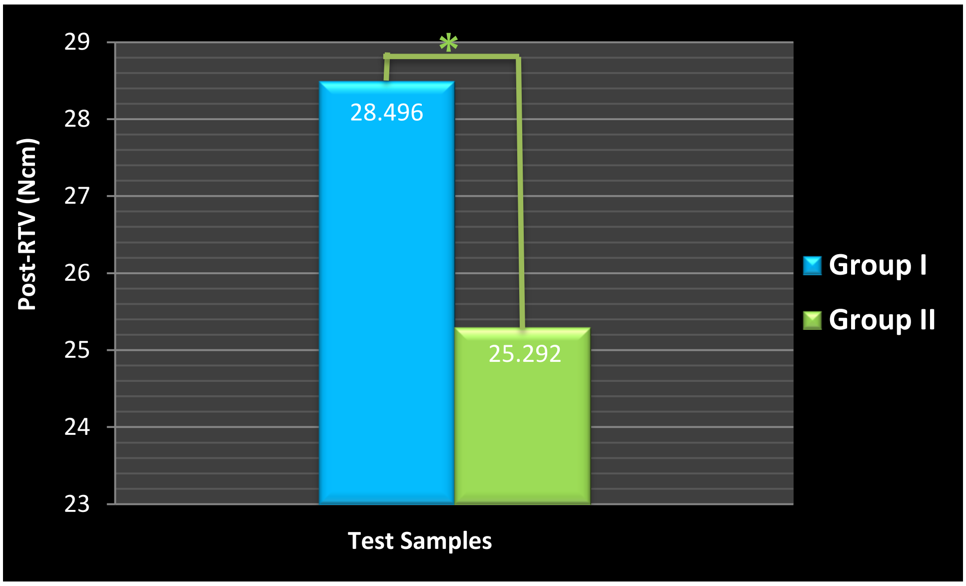
*Significant at 5% level

Graph IX: Comparative evaluation of the mean pre-cyclic loading reverse torque values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples



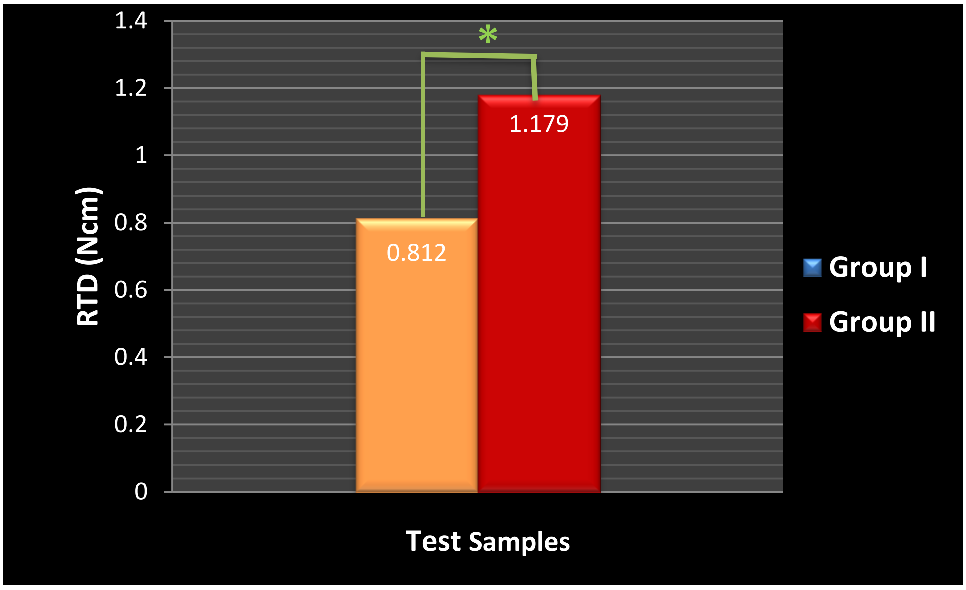
*Significant at 5% level

Graph X: Comparative evaluation of the mean post-cyclic loading reverse torque values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples



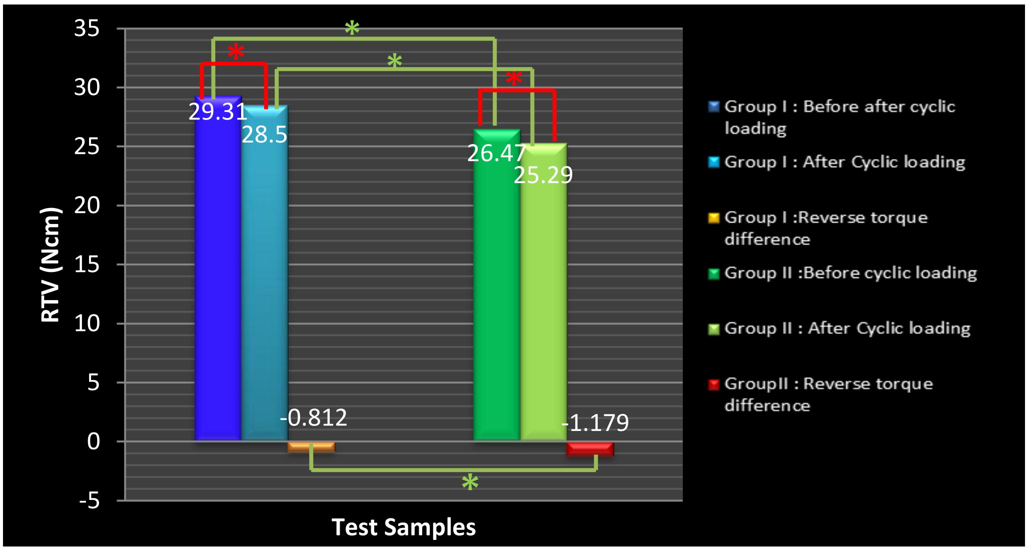
*Significant at 5% level

Graph XI: Comparative evaluation of the mean reverse torque difference values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples



*Significant at 5% level

Graph XII: Overall comparison between mean pre- and post-cyclic loading reverse torque values and the mean reverse torque difference values of Group I (premachined titanium abutments) and Group II (premachined zirconia abutments) test samples



*Significant at 5% level

DISCUSSION

The present in vitro study was conducted to comparatively evaluate the effect of cyclic loading on the reverse torque values of abutment screws for premachined titanium and zirconia abutments using a digital torque meter.

The use of dental implants for restoration of completely and partially edentulous patients is well documented.[7,8,19] A typical two-piece endosseous dental implant unit consists of the following important components, namely, the implant fixture, the abutment and the abutment screw. The first two components are held together by the clamping action of the abutment screw and this unit is called the screw joint as described by Mc Glumphy et al.[54] A majority of partially edentulous situations restored with single-tooth implant supported restorations employ such two piece implant systems. [24, 42,55.]

Such restorations given over these implants can be cement-retained, screw-retained, or a combination of both.[37,41] Cement-retained prostheses provide a less costly and simpler method of fabrication, with a passive restoration, superior esthetics and loading characteristics. [22,37] Although it is commonly used in clinical practice, retrievability of the restoration is the drawback of cement-retained restorations.[37] Screw-retained restorations they provide the advantage of retrievability of restorations and/or replacement of the restorations. [6.22.35,54,55] Although screw-retained crown protocol for a single-tooth two-piece implant is well established, crown complications are common which are mostly associated with implant-abutment screw joint integrity.[10,19,37] A cement-cum-screw retained prosthesis combines the "passivity" feature of a cement-retained prosthesis along with the "retrievability" feature of a screw-retained prosthesis.[41] They also show better marginal adaptation of the cement retained part than the purely cement retained implant prosthesis as a result of the screw-retained abutment seating the restoration.[37] With this restoration design, loosening and fracture of abutment screws is not a severe complication, as it is unnecessary to remove the overlying restoration to gain access to the screw and hence the implant restorations may not be damaged or destroyed in the process.[55]

Traditionally, for anterior single implant- supported restorations, premachined titanium abutments have been used as they displayed superior mechanical properties and excellent biocompatibility.[14,18] The increase in esthetic demands, together with the successful outcome of current implants, has renewed interest in the search for newer materials with enough mechanical properties and better esthetic qualities.[4,16,36] Ceramics for both abutments and restorations are the preferred material of choice. Ceramic abutments were introduced to overcome the esthetic drawbacks of titanium abutments as the grey color was transmitted through the peri-implant soft tissue, especially with thin gingival biotypes.[1,5,15,30,32,52] Zirconia is more commonly used as an esthetic abutment material owing to its superior mechanical and optical properties when compared to alumina.[5,12, 34, 36] Zirconia is now available both as premachined as well as custom-machined (CAD-CAM) abutments. [5, 15, 53] Additionally, these abutments are also non-toxic, have good tissue compatibility and intrasulcular adaptability[56] and accumulate fewer bacteria than commercially pure titanium .[1]

The stability of the connection between the different implant parts is important for the overall success of the prosthetic restoration(s). This is especially true for single-tooth restorations, where a strong interlock between the abutment and implant is necessary. [27, 29, 42, 49] A screw is responsible for two opposite tasks. One, the screw needs to be firmly fixed to withstand loading. Two, it also needs to be retrievable for servicing and/or replacement of components above the fixture and hence, needs to be loosened. Balancing these two opposite requirements is difficult using a screw.[55] Therefore, irrespective of whether such restorations are screw-retained, cement-retained or a combination of these two designs, the threat of abutment or retaining screw loosening remains a potential problem .[9,15,21,27,28,,29,33,42,49,50,55]

An important mechanical factor that prevents abutment screw loosening and fracture is to achieve optimal screw joint “preload” during tightening of the components. [33,50,54] Preload is defined as the tension generated in an abutment screw upon tightening and is a direct determinant of the clamping force. [8,24,28,33,50,54,55] The clamping force keeps the components together. [33,50,54] Preload creates a compressive force at the following interfaces: abutment screw head - abutment, abutment - implant, and abutment - implant thread interfaces.[10] It must be maintained and should fluctuate as little as possible to prevent the joint from separating.[42] The screw loosens only if the outside forces trying to separate the parts are greater than the forces keeping them together. These disengaging forces are called joint separating forces.[24,42,54]

Joint separating forces do not have to be eliminated to prevent screw loosening. They must only remain below the threshold of the established clamping force. If the joint does not open when a force is applied, the screw does not loosen. Hence, the two primary factors involved in keeping implant screws tight are maximizing the clamping force and minimizing joint separating force.[8,24,42,54] Occlusal loading is considered the most detrimental factor affecting preload including functional and parafunctional loading.[55] The external load causes the vibration and micromovement in the screw joint that leads to the reduction of preload and ends with screw loosening.[8,24,50,54]

A screw could also loosen through settling effect. It is also called "embedment relaxation" which plays a critical role in screw stability. It results because no surface is completely smooth. No matter how carefully machined an implant surface is, it is still slightly rough when viewed under microscope. Settling occurs when the rough spots flatten under load, since they are the only contacting surfaces when the initial tightening torque is applied. The extent of settling depends on the initial surface roughness, surface hardness and magnitude of the loading forces. When the total settling effect is greater than the elastic elongation of the screw, the screw works loose because there are no longer any contact forces to hold it in place.[2, 24, 42, 54,55] This can result in loss in tightening torque by 2 to 10%.[42,50,54] Breeding et al and others have proposed retightening of abutment screws after a waiting period of ten minutes as a routine clinical procedure, to minimize this risk.[10,28,42,50,54,55]

The relationship between applied torque and screw preload is affected by many variables, including screw material properties and diameter, screw configuration geometry, and ccoefficient of friction of the 2 contacting surfaces (thread hardness, surface finishes, lubricant quantity and properties and tightening speed).[48] Clinically, variations in torque delivery system, operator technique, presence of oral fluids, speed of tightening, and the use of hand snug tightening before final torque driver tightening are all possible sources of variation in the achievement of optimal preload at the implant/abutment screw joint. [35, 48,50]

Screw loosening during function favours the misfit between implant and abutment which results in various biologic and mechanical consequences.[50] Micromotion during function compresses the screw head against its seat in the implant, thereby reducing the frictional forces in thread by wearing down the microscopically rough areas of the contacted surfaces and results in srew loosening.[2,5,8,14,24,27,30,33] Joint separation force may exceed preload when an implant-abutment assembly is under nonaxial loading due to position or angle of implant, or in the presence of excessive occlusal forces such as bending overload and shearing stress. [50] Biologic complications such as increased leakage, gingivitis and bone loss have been reported to result from a poorly adapted implant-abutment interface. Mechanical complications include damage to screw thread, screw fracture, abutment rotation and breakage.[2,6,25, 44] Anterior teeth bear only about one third to one fourth of the greatest bite force in the posterior region.[15] However, the palatal surface of the anterior teeth provides a vertical “ramp” for the mandibular anterior teeth through protrusive and lateral excursions. Thus, most occlusal loads applied are at an angle to the long axis of the implants which might result in screw loosening. [21, 24]

A cyclic loading test is intended to simulate components in function, which permits analysis of possible interaction between abutment screw and loading. Researchers have tested the effect of cyclic loading on different aspects such as, screw loosening, microgap at the interface, surface changes on implant platform and/or screw channel and microbiological assessments.

Screw loosening can be measured at various time intervals objectively by recording the reverse torque value or detorque value of a screw. [2,15,21,27,28,29,49,50,55] It is measured by applying a counter- clockwise twisting or loosening movement to a right-hand threaded commercial implant. [55] It is a measurement of the remaining preload in the abutment screw.[13] Measurement of reverse torque value of a screw is significant because it gives us an idea about the torque required to loosen a tightened screw.[2] The more closer it is to the applied torque, the better is the maintenance of preload. Measurement of reverse torque value (RTV) has been accomplished using a torque meter which can be either an analogue type [2,8,9,24,28,46,50] or more recently a digital type. [6,17,21,29,40] The latter has the advantage of higher accuracy levels coupled with data storage and transfer facility.

The type of implant-abutment connection design may also affect screw loosening following cyclic loading. A recent systematic review has correlated abutment screw loosening with plastic deformation of the screw, regardless of the geometry of the implant-abutment connection. [21, 29, 31,49] Tsuge T and Hagiwara Y[50] stated that there is no conclusive evidence yet that internal anti-rotation configurations are better than external in resisting screw loosening following cyclic loading. They have attributed this to the availability of abundant literature on abutment screw joint stability in external hexagon implant systems.[8,9,13,21,27,28,29] Comparatively there are very few studies which report on screw loosening in internal hex implants,[10,21] which may account for a lack of conclusive and convincing evidence in this regard. Tsuge T and Hagiwara Y[50] have stated that it is still relevant and necessary to continue examining preloads prior to and following loading of various internal hex implant systems. Most of the available data are related to premachined titanium abutments with different types of screws.[6,10,28,50,27] There is a reported loss of preload upto 20% for the titanium screws and 50% for the gold screws.[50] This indicates that titanium screws are better able to resist to preload loss.[48,50] Studies on the effect of cyclic loading on the reverse torque value of premachined zirconia abutments are sparse.[12,15] Moreover, data comparing the effect of non-axial cyclic loading on the reverse torque values of both premachined titanium and premachined zirconia abutments in a single study is lacking.

In view of the above, the aim of the present in vitro study was to comparatively evaluate the effect of cyclic loading on the reverse torque values of abutment screws for premachined titanium and zirconia abutments using a digital torque meter.

In the present study, titanium dental implants (ADIN Dental Implants, Israel) of 3.75mm diameter with standard platform and 11.5mm length and an internal hexagon design were employed. Titanium dental implants were used as titanium continues to be the most commonly available material for implant fixtures. Although this was an in vitro study, sterile implants were used. All the implants employed were of the same dimensions to maintain standardisation.

The type of connection used in the present study was the internal hexagon. The internal hexagon configuration has the advantage of reduced vertical height from implant platform to the top of the abutment, distribution of lateral loading deep within the implant leading to a better-shielded abutment screw and long internal wall engagement that creates a stiff, unified body to resist joint micromovement when compared to external hexagon connection implant systems.[7, 14,24,50,55] Since studies similar to the present study are lacking with the internal connection design, this geometry was chosen.

The implants were embedded in autopolymerizing methyl methacrylate resin as it exhibits an elastic modulus similar to that reported for trabecular bone (1.95 GPa).[56] The entire implant was submerged except for 1 mm at the crest module to allow easy visualization.

Premachined titanium (ADIN Dental Implants., Israel) and premachined zirconium (ADIN Dental Implants., Israel) esthetic abutments were used in the present comparative study for reasons mentioned earlier. Both these abutments were from the same manufacturer as that of the titanium implant, to avoid the potential impact of interchangeably used abutments of other systems on the screw loosening as recommended by Kim SK et al. [23]

Torque tightening of screws was done as this is the method followed in prosthetic dentistry.[11] The mode of torque application by the clinician is also an important consideration. Torque can be applied manually or by a mechanical device.[20] It has been shown that the average torque delivered by a manual driver within 10Ncm. [42,54] For torque levels greater than 10Ncm a mechanical device such as a torque wrench is usually required.[42] To ensure accurate and reproducible applications and measurements of torque in in-vitro studies, a torque gauge or a torque meter is employed. These gauges can either be of an an analogue or digital type. [2,8,9,24,28,50] A digital torque meter has the advantage of higher accuracy levels coupled with data storage and transfer facility. It also can measure even small changes in the torque values upto 0.05 Ncm both during torqueing as well as during detorquing procedures which is a limitation with the analogue type. It is a reliable tool, both for ensuring that the desired torque is applied as well as for measuring any small changes from this applied torque. Hence in the present study, a calibrated digital torque meter was used for ensuring accuracy while torquing as well as during measuring the reverse torque values.

All the abutments used in the present study were connected to their corresponding implants and torqued to 35 Ncm as this was recommended by the manufacturer as the optimum preload. The screws were tightened to the desired torque in the very first attempt since friction is higher for the first tightening and loosening of a screw, and after repeated tightening and loosening cycles, friction decreases.[33,42] One time screw retightening after ten minutes was done [10,28,42,50,54,55] and this was considered sufficient.[24]

In the present study, the reverse torque values were measured twice for the each test sample, once before and once after cyclic loading. These were designated as pre-cyclic loading reverse torque values (pre-RTV_1 and pre-RTV_2) and post-cyclic loading reverse torque values (post-RTV_1 and post-RTV_2) respectively. The pre-cyclic loading reverse torque value was measured five minutes later as recommended in previous studies.[28,30] Retightening of the abutment screws after the initial measurements was done following the protocol prescribed in previous studies. [10,28,50,54,55]

To simulate clinical conditions for transfer of occlusal load to the abutments, cement-cum-screw retained Ni-Cr cast crowns were cemented over each individual abutment. The cast crowns were contoured to resemble a central incisor and to facilitate easy placement and stabilization of the stylus of the custom-made cyclic loading machine. A 30^{o} inclination was given to simulate the functional stresses along the central incisor root angulation.[56] The abutment screw channel was kept open to allow easy access of the screw head during measurement of post-cyclic loading reverse torque value.

In the present study, a cyclic loading test was performed to simulate the components in function, which permitted the analysis of possible interaction between loading and the change in preload as obtained by the reverse toque values. To accomplish this, a custom-made cyclic loading machine was fabricated with specifications as reported in literature. [23, 50,56] Before beginning each test, grease was used to reduce friction and wear at the loading point.[27,28] The machine was calibrated such that cyclic load between 0 to 109 N was applied at a loading rate of 1.25 Hz for 2520 minutes corresponding to 1,89,000 cycles, as per that followed in previous studies. [23,28,50] Breeding et al reported that mechanical failures like screw loosening tend to occur early, usually within the first month of function.[10] Therefore, a 6 month simulation for cyclic loading was considered sufficient for the present study.

Following cyclic loading, each test sample was subjected to visual and tactile inspection for any deformation, decementation and/or abutment rotation or loosening. None of the 20 test samples exhibited any of the above. The post-cyclic loading reverse torque values were measured and the respective mean pre and post-cyclic loading measurements were obtained for both the test groups. Reverse torque difference (RTD_1 and RTD_2) was obtained to compare the change in pre and post-cyclic loading reverse torque values within each test group.

The mean pre-cyclic loading reverse torque value for Group I test samples was 29.3080Ncm and that for Group II was 26.4710Ncm. There was an appreciable reduction in preload from the applied torque of 35Ncm for both the test groups. For Group I (premachined titanium abutments) upto 16.2% of the applied preload was lost. This loss in preload is in line with previous documented evidence which states that the loosening torques of abutment screws are lower than their tightening torque due to embedment relaxation. [28,29,35,42,44] Also, initial tightening and loosening sequences remove spurs and edges off the threads that are produced during the milling and tapping of the screws and implants.[33] This loss in preload observed is within the limits quoted in literature of 20% for titanium abutments connected with titanium screws.[50] The loss in preload was greater for premachined zirconia abutments (24.37%) which can be attributed to the material and machining differences between zirconia abutments and titanium screws. A study by Al-Turki et al [2] states that only 75% of the applied torque is retained onto single implants without the application of any simulated functional load. When viewed in this perspective, the zirconia abutments also maintained upto 76% of the applied torque.

The mean post-cyclic loading reverse torque value for Group I test samples was 28.4960 Ncm and that for Group II was 25.2920 Ncm. The reverse torque difference for Group I test specimens was found to be -0.8120 Ncm and that for Group II was found to be -1.1790 Ncm. On comparison, the difference between the pre- and post-cyclic loading reverse torque values for both Group I and Group II was found to be statistically significant ($p<0.05$).
Previous studies evaluating the pre- and post-cyclic loading reverse torque values for premachined titanium abutments have reported a significant decrease in values after cyclic loading for both external and internal hex connections.[6,8,10,21,27,28,29,50] The finding in the present study for premachined titanium abutments are in line with those obtained with the above studies.

Similar studies for premachined zirconia abutments are lacking to obtain direct comparisons. Gehrke et al[15] studied the effect of loading on zirconia abutments by FEM analysis. They reported a significant decrease in post-cyclic loading reverse torque values of zirconia abutments after 5 million loading cycles. The results obtained in the present study are similar to that obtained by Gehrke et al, [15] although the study design is different. The present results are also in line with the loss in preload observed generally for any screw joint.

On comparison between the respective mean pre- and post-cyclic loading reverse torque values for Group I and Group II test samples, they were found to be statistically significant ($p < 0.05$). There is greater loss of preload for premachined zirconia abutments both before and after cyclic loading as compared to premachined titanium abutments. Documentation comparing the pre- and post-cyclic loading reverse torque values of premachined titanium abutments and premachined zirconia abutments is lacking to obtain direct comparisons. These results can be attributed to the fact that milling of zirconia abutments is not as perfect as that of titanium abutments which could result in greater settling effect when tightened to titanium implants.[12] Also, there was a difference in the number of screw threads, even though they were from the same manufacturer. Nigro F et al[35] reported better resistance to preload loss when zirconia abutments were tested in a wet environment as compared to a dry one. The impact of the difference in number of screw threads and the testing environment on the reverse torque values needs to be investigated further. Further, Klotz MW et al[30] concluded that the wear between a zirconia abutment and a titanium implant is 8.3 times greater than that occurring with titanium abutment. Whether this factor would have played any role in the results obtained in the present study also needs further investigation.

Within the limitations of this study, both premachined titanium abutments and premachined zirconia abutments had a loss in preload both before and after cyclic loading. Cyclic loading resulted in a significantly greater loss in reverse torque value of zirconia abutments as compared to titanium abutments.

One of the limitations of the present study was that only a 6 month simulation of cyclic loading was performed under dry conditions. Accurately simulating the normal human functional parameters in in-vitro studies is both time consuming and technically challenging[54]. A longer loading period may affect the screw joint differently. The effects of cyclic loading on parameters like, changes in microgap, microbial leakage, bending flexural strength were not concomitantly evaluated. SEM analysis of the abutment screw before and after cyclic loading might have shed more light on the microscopic wear down of the screw threads due to settling effect and micromotion during cyclic loading. Further, aging of zirconia has been suggested to cause a progressive transformation of the metastable tetragonal phase into the monoclinic phase, causing degradation of the mechanical properties.[34]

Future research can include the effect of cyclic loading on the reverse torque values comparing cast abutments, CAD-CAM milled ceramic abutments with premachined abutments using a larger sample size. Influence of the number of abutment screw threads on screw loosening needs to be evaluated. Since there is no scientific support for the clinical belief that screw loosening alone contributes to clinical problems, in vivo studies regarding bone response to screw loosening can also be evaluated. More studies assessing the horizontal and rotational misfit as well as stress transfer of zirconia abutments will likely provide better information regarding their clinical use and enhance the results obtained in the present study. Future studies incorporating the above considerations are recommended to add merit to the conclusions obtained with the present study.

CONCLUSION

The following conclusions were drawn based on the results obtained in the present in-vitro study, which was conducted to comparatively evaluate the effect of cyclic loading on the reverse torque values of abutment screws for premachined titanium and zirconia abutments using a digital torque meter.

1. The mean pre-cyclic loading reverse torque value of abutment screws for premachined titanium abutments (Pre-RTV_1) was found to be 29.3080 Ncm.
2. The mean post-cyclic loading reverse torque value of abutment screws for premachined titanium abutments (Post-RTV_1) was found to be 28.4960 Ncm.
3. The mean reverse torque difference (RTD_1) of abutment screws for premachined titanium abutments was found to be -0.8120 Ncm.
4. The mean pre-cyclic loading reverse torque value of abutment screws for premachined zirconia abutments (Pre-RTV_2) was found to be 26.4710 Ncm.
5. The mean post-cyclic loading reverse torque value of abutment screws for premachined zirconia abutments (Post-RTV_2) was found to be 25.2920 Ncm.
6. The mean reverse torque difference (RTD_2) of abutment screws for premachined zirconia abutments was found to be -1.1790 Ncm.

7. On comparison, difference between the pre-cyclic loading and post-cyclic loading reverse torque values of abutment screws for premachined titanium abutments (-0.8120 Ncm) was found to be statistically significant.
8. On comparison, difference between the pre-cyclic loading and post-cyclic loading reverse torque values of abutment screws for premachined zirconia abutments (-1.1790 Ncm) was found to be statistically significant.
9. On comparison, the mean pre-cyclic loading reverse torque value of abutment screws for premachined titanium abutments (29.3080 Ncm) was higher than that of premachined zirconia abutments (26.4710 Ncm) and this difference in mean values was found to be statistically significant.
10. On comparison, the mean post-cyclic loading reverse torque value of abutment screws for premachined titanium abutments (28.4960 Ncm) was higher than that of premachined zirconia abutments (25.2920 Ncm) and this difference in mean values was found to be statistically significant.
11. On comparison, the mean reverse torque difference of abutment screws for premachined titanium abutments (-0.8120 Ncm) was lesser than that of premachined zirconia abutments (-1.1790 Ncm) and this difference was found to be statistically significant.

12. On overall comparison, both the respective mean pre- and post-cyclic loading reverse torque values of abutment screws for premachined titanium abutments were significantly higher than that of premachined zirconia abutments. Cyclic loading had a significantly greater effect in decreasing the reverse torque value (higher RTD) for premachined zirconia abutments than for premachined titanium abutments.

SUMMARY

The present in-vitro study was conducted to comparatively evaluate the effect of cyclic loading on the reverse torque values of abutment screws for premachined titanium and zirconia abutments using a digital torque meter.

Twenty titanium implants (Standard platform) (n=10) were embedded individually using autopolymerizing acrylic resin in custom made stainless steel blocks and randomly divided into two groups of ten each (n=10). In Group I, ten titanium abutments (Standard platform, internal hex) were connected to their corresponding implants and torqued to 35 Ncm using a digital torque meter. In Group II, ten zirconia abutments (Standard platform, internal hex) were connected similarly to their corresponding implants. Pre-cyclic loading reverse torque values were measured individually for both Group I and Group II samples using a digital torque meter. Nickel-chromium cast crowns were fabricated for all the twenty samples and cemented with resin-modified glass ionomer cement with an access to the screw channel.

Each test sample was secured in a jig and positioned in a custom-made cyclic loading device at an angulation of 30^o, and subjected to cyclic loading for loads between 0 and 109 N for 1,89,000 cycles simulating 6 months of function. The post-cyclic loading reverse torque values were measured individually for both Group I and Group II test samples using a digital torque meter in a similar manner as was followed for the pre-cyclic loading measurements. The difference between pre-cyclic loading reverse torque value and post-cyclic loading reverse torque value was calculated for all the 20 test

samples. The mean reverse torque difference was obtained for both Group I and Group II to assess the change in reverse torque values before and after loading. The results obtained were tabulated and statistically analysed.

The respective mean pre- and post-cyclic loading reverse torque values of premachined titanium abutments were higher than those for premachined zirconia abutments and the difference was statistically significant. The post-cyclic loading reverse torque values of the premachined titanium samples were lesser than its mean pre-cyclic loading reverse torque value and their difference was statistically significant. The mean post-cyclic loading reverse torque value of the premachined zirconia samples was also lesser than the mean pre-cyclic loading reverse torque value and their difference was statistically significant. The mean reverse torque difference of premachined titanium samples was lower than that of premachined zirconia abutments and the difference was statistically significant.

The results in the present study indicates that both premachined titanium and premachined zirconia abutments exhibited a decrease in reverse torque values after cyclic loads simulating six months of function. The decrease in reverse torque value was significantly more in zirconia abutments than titanium abutments. However, the reverse torque value had not reduced to a critical level to cause visible screw loosening for both the abutments. Thus choice of abutment material in the anterior esthetic zone can be left to the operator's preference and individual clinical indication.

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